APPENDIX B

STATEWIDE OR REGIONAL APPROACHES

1. **GEORGIA**
   The Georgia Lake Standards Legislation (M. Walker)
2. **MINNESOTA**
   Ecoregional Classification of Minnesota Lakes (S. Heiskary)
3. **NORTH CAROLINA**
   Nutrient Control in North Carolina's Lakes and Reservoirs (D. Reid)
4. **SOUTH DAKOTA**
   A Watershed Approach - South Dakota (W. Stewart)
5. **VIRGINIA**
   The Virginia Nutrient Enriched Waters Designation (J. Gregory)
6. **WISCONSIN**
   Wisconsin Lake Phosphorus Criteria (G. Searle)
7. **TENNESSEE VALLEY**
   The Tennessee Valley Authority Reservoir Vital Signs Monitoring Program: Chlorophyll and Nutrients Rating Scheme (N. Carriker and D. Meinert)
8. **BRITISH COLUMBIA**
   The British Columbia Water Use Based Approach (R. Nordin)
9. **ONTARIO**
   Rationale For a Revised Phosphorus Criterion for Precambrian Shield Lakes in Ontario (N. Hutchinson)

LAKE OR RESERVOIR SPECIFIC APPROACHES

10. **DILLON RESERVOIR, COLORADO**
    Dillon Reservoir Phosphorus Standard, Load Allocation, and Crediting System (R. Ray)
11. **EVERGLADES, FLORIDA**
    Interim Phosphorus Standards for the Everglades (W. W. Walker)
12. **LAKE CHAMPLAIN, VERMONT, NEW YORK, AND QUEBEC**
    Total Phosphorus Criteria for Lake Champlain (E. Smeltzer)

1. Georgia Lake Standards Legislation

by Max Walker, Georgia Department of Natural Resources

In 1990, the Georgia General Assembly adopted a lake standards bill (O.C.G.A. 12-5-23.1). A copy of the bill is reproduced below. The legislation requires that the Georgia Environmental Protection Division (EPD) conduct comprehensive studies and develop water quality standards for lakes with a surface area of 1,000 acres or more. The General Assembly provided no funds to support implementation of the legislation. Phase I Diagnostic-Feasibility Studies have been completed by EPD using USEPA Clean Lakes funds on Lakes West Point, Walter F. George, and Jackson. Based on the information collected as a part of the Phase I studies, water quality standards were developed and adopted for each lake. Phase I studies are ongoing on Lakes Lanier, Allatoona, Blackshear, and Carters. At such time as the studies are completed, the EPD will use the information and develop and adopt water quality standards for these lakes.

12-5-23.1 Water quality standards for lakes; monitoring; studies and reports; development, approval, and publication of water quality standards.

(a) As used in the Code section, the word “lake” means any publicly owned lakes or reservoir located wholly or partially within this state which has a normal pool level surface average of 1,000 or more acres.

(b) The director shall establish water quality standards for each lake which require the lake to be safe and suitable for fishing and swimming and for use as a public water supply, unless a use attainability analysis conducted within requirements of this article demonstrates such standards unattainable.

(c) For purposes of this subsection, a multiple parameter approach for lake water quality standards shall be adopted. Numerical criteria including, but not limited to, those listed below shall be adopted for each lake:

(A) pH (maximum and minimum):

(B) Fecal coliform bacteria;

(C) Chlorophyll *a* for designated areas determined as necessary to protect a specific use;

(D) Total nitrogen;

(E) Total phosphorus loading for the lake in pounds per acre feet per year; and

(F) Dissolved oxygen in the epilimnion during periods of thermal stratification.

(d) The standards for water quality of each lake shall take into account the geographic location of the lake within the state and the location of the lake within its watershed as well as horizontal and vertical variations of hydrological conditions within each lake. The director shall also establish nutrient limits for each of the lakes’ major tributary streams including streams with permitted discharges. Such limits shall be consistent with the requirements of subsection (b) of this Code section and shall be established on the basis of accepted limnological techniques and as necessary in accordance with the legal and technical principles for total maximum daily loads. The nutrient limits for tributary streams shall be established at the same time that the lake water quality standards are established.

(e) After water quality standards are established for each lake and its tributary streams, the division shall monitor each lake on a regular basis to ensure that the lake reaches and maintains such standards.

(f) The data from such monitoring shall be public information. The director shall have the authority to close a swimming area if data from samplings indicates, in the opinion of the director, that such action is necessary for public safety.

(g) Provided funds are available from any source, there shall be a comprehensive study of each lake prior to adopting lake water quality standards for the lake. Study components and procedures will be established after consultation with local officials and affected organizations. The comprehensive study for Lake Sidney Lanier, Lake Water F. George, and West Point Lake shall be initiated during 1990. At least three comprehensive studies for participating lakes shall be initiated in each subsequent year. The duration of each study shall not exceed two years. A scientific report on each comprehensive study shall be published within 180 days after the completion of the study. Draft recommendations for numerical criteria for each of the water quality parameters will be simultaneously published, taking into account the scientific findings. A public notice of the draft recommendations, including a copy of the recommendations, will be made available to the public. Public notice in accordance with Chapter 13 of Title 50, the "Georgia Administrative Procedure Act," shall be provided for such recommendations. The notice shall be made available at least 30 days prior to board action in a regional public library or county courthouse. The recommendations will be provided to persons submitting a written request. A comment period of not less than 45 days nor more than 60 days will be provided.

(h) The director or the director's designate shall conduct a public hearing within the above-referenced comment period in the vicinity of the lake before the final adoption of lake water quality standards for the lake. The director shall announce the date, time, place, and purpose of the public hearing at least 30 days prior to the hearing. A ten-day period subsequent to the hearing will be allowed for additional public comment.

(i) The Department of Natural Resources will evaluate the comments received during the comment period and during the public hearing and will then develop recommended final standards and criteria for submission to the Board of Natural Resources for consideration and approval.

(j) The final recommendations of the director for lake water quality standards shall be made to the Board of Natural Resources within 60 days after the close of the comment period subsequent to the public hearing provided for in subsection (h) of this Code section. The standards, with such modifications as the board may determine, shall be considered for adoption by the Board of Natural Resources within 60 days after receiving the recommendations from the director. Such standards shall be published by the department and made available to all interested local government officials and citizens of the area served by the lake.

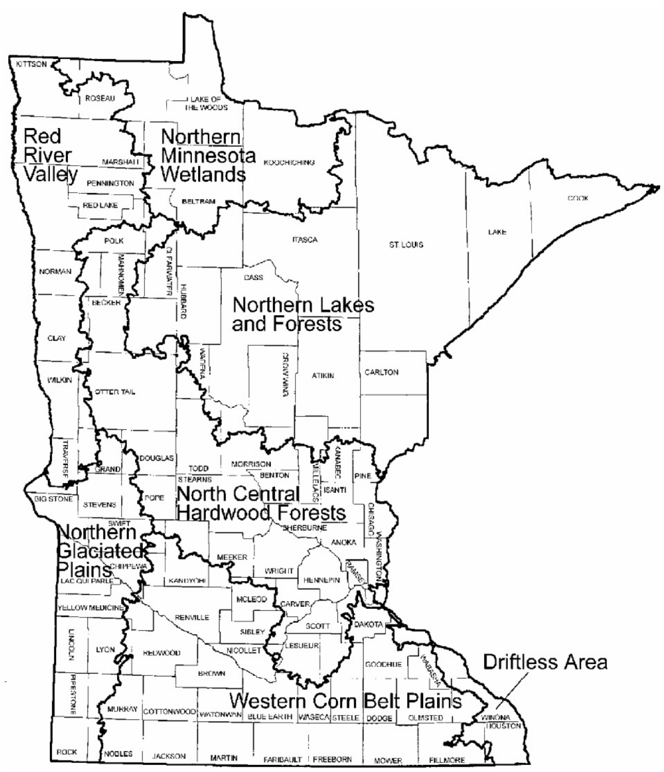
(k) At the discretion of the direction, comment periods and deadlines set forth above may be extended, but in no circumstance shall more than one year elapse between the completion of the lake study and the adoption of the final recommendations. (Code 1981, § 12-5-23.1, enacted by Ga. L. 1990, p. 1207, § 1.)

2. Ecoregional Classification of Minnesota Lakes

by Steven Heiskary, Minnesota Pollution Control Agency

Minnesota has over 12,000 lakes spread across diverse geographic areas. Previous studies had shown distinct regional patterns in lake productivity associated with regional differences in geology, vegetation, hydrology, and land use (Heiskary and Wilson, 1989). Minnesota contains seven ecoregions (Omernik, 1987), and four of the ecoregions contain 98 percent of the lakes. These four ecoregions are the Northern Lakes and Forest (NLF), North Central Hardwood Forest (NCHF), Northern Glaciated Plains (NGP), and Western Corn Belt Plains (WCBP) (Figure 1). Minnesota uses these ecoregions as the framework for analyzing data, developing monitoring strategies, assessing use patterns, and developing phosphorus goals and criteria for lakes (Heiskary, 1989).

Figure 1: Minnesota Ecoregions



The Minnesota Pollution Control Agency (MPCA) and several other groups collected data on chlorophyll *a* concentrations and several water quality parameters (total phosphorus, total nitrogen, and Secchi transparency) in 90 reference lakes between 1985 and 1987. Secchi transparency data were collected mostly by volunteer participants in the Citizen Lake Monitoring Program. Reference lakes were chosen to represent minimally impacted sites within each ecoregion. Criteria used in selecting reference lakes included maximum depth, surface area, fishery classification, and recommendations from the Minnesota Department of Natural Resources (Heiskary and Wilson, 1989). Lake morphometry had previously been examined. In addition to the reference lake data base, MPCA examined a statewide data base containing data collected by these same groups on approximately 1,400 lakes form 1977 to 1987.

Differences in morphology, chlorophyll *a* concentrations, total phosphorus, total nitrogen, and Secchi transparency were found among lakes in the four ecoregions in both studies. Lakes in the two forested ecoregions (NLF and NCHF) are deeper (median maximum depth of 11 meters), with slightly smaller surface areas (40 to 280 ha), than those in the plains ecoregions (NGP and WCBP). Lakes in the two plains ecoregions were typically shallow (median maximum depth of 3 meters) with larger surface areas (60 to 300 hectares).

Box-and-whisker plots for chlorophyll *a* and water quality measurements in the reference lake study paralleled the morphological differences seen among the ecoregions (Heiskary and Wilson, 1989). The two plains ecoregions had significantly higher chlorophyll a levels than either of the two forested ecoregions. Results of the statewide data base analysis showed these same trends. The results of these two data base analyses support the use of ecoregions in developing frameworks for data analysis, monitoring strategies, assessing use patterns, and developing phosphorus goals and criteria for lakes.

3. Nutrient Control in North Carolina's Lakes and Reservoirs

by Dianne Reed, North Carolina Department of Environmental Management

North Carolina's approach to the control of eutrophication could serve as a model for how to use specific criteria and special programs along with special use classifications to achieve restoration and protection of lakes and reservoirs under the Clean Water Act. This approach provides the flexibility necessary to develop management strategies for the wide variety of responses to nutrient loading seen in North Carolina lakes and reservoirs.

In the late 1970s, in response to extensive algal blooms in a coastal river (Chowan River), which has many characteristics similar to a lake, North Carolina adopted a chlorophyll *a* standard of 40 µg/L for warm waters and 15 µg/L for cold waters as part of its water quality standards. Another important aspect of this standard was the inclusion of a narrative that gives the Director of the Division of Water Quality authority to prohibit or limit any discharge into surface waters if the Director determines that this discharge would contribute to exceedances of the chlorophyll *a* standard. This narrative has allowed the inclusion of more stringent nutrient limits in several permits throughout the state without reclassification or development of basinwide plans.

As a result of the work done on the Chowan River, the Division established an algal bloom program. This program analyzes phytoplankton, chlorophyll *a,* and nutrients, as well as other parameters from lakes, reservoirs, and slow-moving rivers throughout North Carolina. Data collected through this program resulted in a legislative ban on phosphate detergents for the entire state.

Another action that contributed significantly to nutrient control in North Carolina was the development of the Nutrient Sensitive Waters (NSW) supplemental classification. The NSW supplemental classification allows the state to seek abatement of the point and nonpoint source releases of nutrients upstream from a priority water body through the rule-making process. There are a total of six areas that have been declared NSW in North Carolina.

Two of the areas were major reservoir watersheds, Falls of the Neuse Lake and Jordan Lake. Sufficient data were available to adapt nitrogen, phosphorus, and chlorophyll *a* loading/response models and to assess the impact of predicted population growth and changes in wastewater inputs and land use. As a result of the modeling, new wastewater treatment plants, as well as major existing ones, are required to meet a total phosphorus effluent limitation of 2.0 mg/L.

Nonpoint pollution sources also are addressed. The state legislature created a targeted agricultural water quality cost sharing program to provide an incentive for producers and growers to use nutrient abatement practices. The program provides a 75 percent cost share and has been enthusiastically received. To control urban nonpoint sources, the state issued developmental (land use) guidelines to counties and municipalities in the lake watersheds for controlling urban pollutants through local ordinances. With the NPDES stormwater permit program and water supply watershed use designation, North Carolina is well positioned to control eutrophication in its lakes and reservoirs.

Another way that North Carolina is addressing eutrophication of its waters is within the basinwide water quality management process and plans. One example of how these management plans are being successfully used is in Lake Wylie (Catawba River Basin). In 1992, North Carolina documented eutrophic conditions in Lake Wylie and several of its major tributaries. Both point and nonpoint pollution sources were identified as contributing to high nutrient loadings resulting in violations of the State chlorophyll *a* standard. To address eutrophication in Lake Wylie, the State adopted a point and nonpoint nutrient control strategy for the Lake Wylie watershed. The basis for these actions was the chlorophyll *a* standard and its caveat allowing the Director to require nutrient controls at his or her discretion.

For point sources, the strategy required state-of-the-art nutrient removal for all new or expanding wastewater discharges in the vicinity of the lake. For nonpoint sources, this strategy included targeting of funds from the state's Agricultural Cost Share Program for the Reduction of Nonpoint Source Pollution for implementation of best management practices on agricultural lands in highly impacted watersheds of Lake Wylie.

In conjunction with the 1995 Catawba River basinwide planning effort, the Lake Wylie management strategy was reexamined and updated. As a result of the update, no new discharges will be allowed to the lake mainstem or its tributaries, unless an evaluation of engineering alternatives shows that such a discharge is the most environmentally sound alternative. Any new discharges that meet this requirement will be required to apply advanced removal technology.

New facilities (including expansions) with a permitted design flow of greater than or equal to 1 million gallon per day (MGD) are required to meet monthly average limits of 1 mg/l total phosphorus and 6 mg/l total nitrogen (nitrogen limits to apply for the months April through October only). New facilities and expansions with a permitted design flow of less than 1 MGD but greater than 0.05 MGD are required to meet a total phosphorus limit of 2 mg/l. The industries in the management area are to control TP and TN to best available technology levels as agreed upon with state regulators. It is entirely possible that discharges could receive more stringent nitrogen and phosphorus limits on a case-by-case basis if supported by sampling data and approved by the Director.

To reduce nutrient enrichment in the two most eutrophic arms of Lake Wylie, additional recommendations were made for point source discharges to the Catawba Creek and Crowders Creek watersheds. In both watersheds, incentives are to be established to encourage the privately owned facilities to tie on to larger municipal WWTPs.

4. Watershed Approach in South Dakota

by William Stewart, South Dakota Department of Environment and Natural Resources

The State of South Dakota has had ambient water quality standards in place for lakes since the late 1960's. These standards exist in both numeric and narrative forms. Phosphorus is not listed as a parameter in the numeric standards but is covered by the narrative section. At this time, there are no numeric limits on phosphorus on any surface waters of the state.

The Watershed Protection Program is part of the South Dakota Department of Environment and Natural Resources. This program is responsible for nonpoint source pollution control and lake management. The Watershed Protection Program is based on requests for assistance from local groups such as lake associations or conservation districts. Virtually all of the watershed and lake restoration projects in the state are done on a voluntary basis and enforcement is seldom used, except in extreme cases. By far and away, the largest problem for South Dakota lake water quality is sediment and nutrients from agricultural nonpoint source pollution.

The first step in conducting a lake restoration project in South Dakota is the assessment of the lake and its watershed. A typical assessment project is a two-year effort, including intensive water quality monitoring of the lake and tributaries, stream gauging, biological sampling, land-use modeling, and public outreach.

A mathematical relationship developed by Vollenweider and Kerekes (1980) is used to model the relationship between phosphorus inflows and ambient total phosphorus concentrations in the lake. By changing the phosphorus inflows in the equation, corresponding changes in in-lake phosphorus are estimated. In this way, we are able to model changes in chlorophyll *a* concentrations and the response of in-lake phosphorus concentration to the reduction of tributary phosphorus levels.

Once we have determined the target reduction in in-lake phosphorus, we use the Agricultural Nonpoint Source (AGNPS) model to estimate load reductions from the watershed. In order to use the AGNPS program, the watershed is divided into 40-acre cells and 21 parameters are collected for each cell. The model estimates loads of nitrogen, phosphorus, and sediment to the lake. By adding various Best Management Practices to the model, it is possible to determine which practices are needed to reach the estimated watershed phosphorus reduction to produce the desired ambient in-lake phosphorus concentration.

The information from the lake/watershed assessment is used to develop an implementation plan for restoration. The South Dakota Watershed Protection Program has had considerable success with this procedure. The lake and watershed stakeholders generally accept the assessment reports and find them to be useful planning tools in the development of restoration plans.

References

Vollenwieder, R.A. and J. Kerekes, 1980. *The loading concept as a basis for controlling eutrophication*. Philosophy and preliminary results of the OECD Programme on Eutrophication. Prog. Water Technol. 12:3-38.

5. The Virginia Nutrient Enriched Waters Designation

by Jean Gregory, Virginia Department of Environmental Quality

The quality of Virginia's surface waters, particularly those in the Chesapeake Bay drainage area, is affected by the presence of nutrient enrichment. In recognition of this, the State Water Control Board (SWCB), now the Department of Environmental Quality, has developed a strategy to protect the surface waters of the Commonwealth of Virginia from the effects of nutrient enrichment.

In the mid-1980's, the State's General Assembly formed a joint legislative subcommittee to study these problems in the Chesapeake Bay. One of the recommendations in their final report was to direct the SWCB to develop water quality standards by July 1, 1988, to protect Chesapeake Bay and its tributaries from nutrient enrichment. The SWCB decided to expand this standards-setting activity statewide to include other river basins and lakes where there were known nutrient enrichment problems. A second legislative mandate to develop implementation strategies for carrying out these water quality standards was made jointly to the SWCB, which has jurisdiction for point sources, and the Division of Soil and Water, which is responsible for nonpoint source controls. As a result, SWCB developed two regulations that became effective on May 25, 1988. The first established a water quality standard that designated as "nutrient enriched waters" those waters of the Commonwealth that show evidence of degradation due to the presence of excessive nutrients. A companion policy regulation was created to control certain point source nutrient discharges affecting State waters designated as "nutrient enriched waters."

To assist them in developing the water quality standard, the SWCB formed a Technical Advisory Committee (TAC) composed of 19 scientists from east coast universities and the Federal government. There were specific issues the Board was seeking advice on prior to developing these standards, including such issues as whether narrative or numerical standards were needed, appropriate parameters and numerical levels, and the appropriate monitoring, sampling, and evaluation methods.

The SWCB used a variety of policy analysis techniques to obtain recommendations from the committee for the best indicators of nutrient enrichment. First, SWCB mailed a series of three delphi questionnaires to the 19 TAC scientists asking them to identify major issues and thereby reach some consensus on topics to focus on. Responses were anonymous so that the scientists would not bias each other. SWCB followed this process with a two-day spring (May 14-15, 1987) workshop held in Williamsburg by the University of Virginia's Institute of Environmental Negotiation. A summary report was compiled.

The Technical Advisory Committee recommended four parameters that could be used as in-stream indicators of nutrient enrichment. Listed in descending order of importance they are chlorophyll *a*, dissolved oxygen (D.O.) fluctuations, total phosphorus, and total nitrogen. Note that the first two parameters are symptoms of nutrient enrichment rather than direct measurements of nutrients.

Each of these four parameters was considered to develop a recommendation for fresh water lakes.

- *Chlorophyll* a

Most TAC members favored use of a chlorophyll *a* criterion for lakes. A numerical level of 25 µg/l as a monthly average with a maximum one-time exceedence level of 50 µg/l was proposed. These values received general support from the group. There was a discussion about whether the chlorophyll criterion should be based on planktonic chlorophyll only or whether some consideration should be given to macrophytic chlorophyll as well. It was determined that a planktonic measure would be easier to sample and would accurately reflect the eutrophic condition of the lake.

It was suggested that monitoring samples be taken at one-half the Secchi depth as long as that depth was greater than 1 foot. An alternative proposal was to use an integrated mixed layer sample which, according to some members, would yield more reliable results. The use of Secchi depth is, however, a well-recognized and reliable method and it was favored for its simplicity.

TAC members thought the numerical chlorophyll criterion for lakes should be combined with a narrative element that would deal with the problems caused by high chlorophyll levels—taste, odor, and clogged filters at water treatment plants.

- *Dissolved Oxygen*

It was the consensus of the TAC group that due to wide variation in D.O. at different depths and the difficulty this creates in setting standards and sampling techniques, and the fact that D.O. problems are symptoms that would be reflected in other standards, no lake criterion for D.O. should be recommended. The group did agree that a narrative component addressing the conditions associated with D.O. problems should be drafted.

- *Total Phosphorus*

The TAC group suggested two possible lake criteria for total phosphorus in lake waters: a level of 50 µg/l as a weighted mean based on the water mass, or a level of 25 µg/l as a mixed layer mean. These levels were judged to be of equal validity as a measure of total P. (It was noted that if chlorophyll were sampled on a mixed layer basis this might be the preferred approach because the two samples could be taken at the same time.)

- *Total Nitrogen*

The TAC group discussed the possibility of linking the criterion for total nitrogen to the criterion for phosphorus. It was suggested that some N to P ratio could be used or that the nitrogen criterion could be set at ten times the phosphorus criterion. After discussion, the group agreed that no nitrogen criterion should be set. Phosphorus is almost always the limiting factor in the eutrophication of Virginia's warm water lakes, and the group thought a nitrogen criterion would be unnecessary.

Recommendations of the TAC

In freshwater lakes the state should consider setting a chlorophyll *a* criterion of 25 µg/l as a monthly average, with a one-time exceedence level of 50 µg/l with both measured at one-half the Secchi depth (if > 1 foot). This should be combined with a total phosphorus criterion of 50 µg/l as a weighted mean or 25 µg/l as a mixed layer mean. A narrative component should be developed as well to address more general chlorophyll *a* and D.O. problems in lakes.

Taking into consideration the recommendation of the committee, the SWCB decided to base its designations for lakes and all other surface waters on the first three parameters. A reference to these parameters was included in the introduction to the water quality standard regulation for designating nutrient enriched waters. SWCB was intentionally silent on the numerical limits because unacceptable amounts of these parameters could vary depending on the type of water body, whether it were a lake, free-flowing river, or tidal estuary. Because every designation would require an amendment to Virginia's water quality standards, and full public participation is required by the agency and State rules for adopting regulations, SWCB felt that the public would be properly notified in every case of the appropriate scientific and numeric basis for these designations.

Average seasonal concentrations of chlorophyll *a* exceeding 25 mg/l, dissolved oxygen fluctuations, and high water column concentrations of total phosphorus have been the indicators used to date to evaluate the historical data and to identify those waters affected by excessive nutrients. Chlorophyll *a*, a pigment found in all plants, was used as the primary indicator because it indicates the quantity of plant growth.

Based on a review of historical water quality records, the SWCB designated as “nutrient enriched waters” three lakes, one tributary to a lake, nine embayments or tributaries to the Potomac River, the Virginia portion of the Chesapeake Bay, and a large portion of the Bay’s tributaries. Since this initial round of designations, SWCB has amended the standard to designate the tidal freshwater portion of the Chowan River Basin in Virginia. SWCB intends to continue to review these designations and, during each triennial review of water quality standards, will consider additions and deletions to the list. For example, Lake Chesdin is proposed for designation during the current triennial review of the water quality standards regulation.

As SWCB has authority to issue National Pollution Discharge Elimination System (NPDES) permits, and thereby control point source discharges of nutrients, a policy for controlling certain point sources of nutrients to those waters designated as “nutrient enriched” was established. (Another agency, the Division of Soil and Water, developed strategies for managing nonpoint sources of nutrients to “nutrient enriched waters.”) The policy requires certain municipal and industrial organizations that discharge effluents containing phosphorus to maintain a monthly average total phosphorus concentration of 2 mg/L or less. The 2 mg/L limit was based on the following criteria:

- Limits that are readily achievable by chemical addition processes, as demonstrated by experiences in other parts of the country
- Suggested achievable limits for biological phosphorus removal contained in several reports as well as in State pilot plant studies.

SWCB has found that this level of phosphorus removal would result in meeting the 40 percent reduction goal of total phosphorus for point source discharges from Virginia entering into the Chesapeake Bay.

Municipal and industrial dischargers that release phosphorus in concentrations above 2 mg/l to these “nutrient-enriched waters” are subject to this policy if they have a design flow of 1.0 MGD or greater and a permit issued on or before July 1, 1988. These dischargers were required to meet the 2 mg/l effluent limitation as quickly as possible and, in any event, within three years following modification of the NPDES permit. If the discharger voluntarily accepted a permit that required nitrogen removal to meet a monthly average total nitrogen effluent limitation of 10 mg/l for April thorough October, the discharger was allowed an additional year to meet the phosphorus effluent limitation.

All new source dischargers with a permit issued after July 1, 1988, and a design flow greater than or equal to 0.05 MGD that propose to discharge to “nutrient-enriched waters” are also required to meet a monthly average total phosphorus effluent limitation of 2 mg/l. All dischargers to “nutrient-enriched waters” that, at the time of that designation, were subject to effluent limitations more stringent than the 2 mg/l monthly average total phosphorus are required to continue to meet the more stringent phosphorus limitation.

The policy regulation also contains language that allows SWCB to require monitoring of discharges when the permittee has the potential for discharging monthly average total phosphorus greater than 2 mg/l and also allows adjoining States to petition the Board to consider rulemakings to control nutrients entering tributaries to their nutrient-enriched waters.

The policy regulation states that after the point source controls are implemented and the effects of this policy and the nonpoint source control programs are evaluated, the SWCB recognizes that it may be necessary to impose further limitations on dischargers for additional nutrient control to prevent undesirable growths of aquatic plants. This policy can thus be viewed as the first phase of a strategy to protect Virginia’s waters from the effects of excessive nutrients.

6. Wisconsin Lake Phosphorus Criteria

by Greg Searle, Wisconsin Department of Natural Resources

In 1991 the Wisconsin Department of Natural Resources (WDNR) began development of water quality criteria for phosphorus for lakes and impoundments. The Phosphorus Technical Workgroup (PTW) was charged with developing scientifically defensible phosphorus water quality criteria and passing the criteria on to a Technical Advisory Committee for implementation consideration. The PTW has completed the development of phosphorus “numbers” (the use of the term “numbers” will be explained after the development section) and has passed those numbers on to a Watershed Advisory Committee.

Development of Phosphorus “Numbers”

Historical total phosphorus data were obtained from the STORET database for lakes and impoundments across the state. The dataset was censored in the following ways:

- Minimum surface area was equal to or exceeded 25 acres.
- Sample dates were restricted to those collected between June 1 and September 15, inclusive.
- Surface data were utilized and defined as samples that were collected from a depth of four feet or less.

The reduced dataset was further categorized by drainage type and known summer thermal stratification patterns (mixed or stratified). With respect to drainage type, the waterbodies were designated as drainage or seepage waterbodies. The definition of drainage type was associated with the presence or absence of an outlet and not the source of water entering the waterbody.

To account for regional patterns of summer total phosphorus, the STORET data were overlaid on each of 21 sub-ecoregions of Wisconsin proposed by Omernik et al. (1988). Evaluation of these data led to the conclusion that minimal data in many of the sub-ecoregions restricted the ability to accurately derive water quality criteria. Recent efforts of Lillie et. al. (1993) to develop a Trophic State Index (TSI) for Wisconsin lakes showed clear associations between water clarity, chlorophyll *a*, and TP on a regional basis. The PTW agreed that the STORET data should be evaluated using Lillie’s proposed regions.

WDNR staff concluded that a three-way separation (north, central, and south) of phosphorus regions for lakes was supported by the comparison of mean total phosphorus data. When comparing similarly impacted lakes in the proposed North vs. South regions, there was a trend of significance. Mean total phosphorus concentrations in lakes categorized as being moderately or slightly impacted were different, whereas they were not for those lakes categorized as being highly impacted or those that were unranked altogether. This analysis did not support grouping the two regions together. In comparing both the proposed North or the South to the Central region, a consistent difference was not found in mean total phosphorus concentrations. These data clearly indicate that, while the Central region may be grouped with either the North or South Region, it does not bridge the two regions, and therefore supports a different set of water quality standards.

Like the regional inconsistencies observed in the comparative total phosphorus values for lakes, there were also inconsistencies observed in mean total phosphorus values for impoundments. Mean total phosphorus concentrations in the proposed South region were not significantly higher than those for the North. The mean total phosphorus values for the Central region were statistically different when compared with the North and South regions. Since the mean total phosphorus values may be similar in the North and South, but not the North and Central or the South and Central, it was decided to separate the three regions altogether.

Having decided to further evaluate total phosphorus data using the three regions identified by Lillie et al. (1993), the STORET data were combined for each region by drainage type and potential for thermal stratification. Based on PTW consensus, lower quartiles (25 percent quantile) were generated using SAS univariate procedures on all individual total phosphorus values in the censored STORET dataset. Once the lower quartile values were generated, they were further modified by rounding them down to the nearest multiple of five.

Several discussions occurred in previous PTW meetings regarding the significance of using the lower quartile numbers. PTW members exercised their "best professional judgment" and seemed to believe that the lower quartile would provide a conservative estimate of background total phosphorus concentrations in Wisconsin's lakes and impoundments. The members believed that there were more technical means of determining background values (i.e., paleolimnological studies, lake-specific or impoundment-specific modeling, etc.). They acknowledged, however, that there were resource limitations and agreed that the lower quartiles were the best available method for estimating ambient water quality standards that would lead to satisfactory water quality if met. In accepting the concept of lower quartile-based water quality standards, there was unanimous agreement among PTW members that the group would recommend to the Watershed Advisory Committee that whatever administrative rule revisions were eventually made, there must be language that allows for the development of site-specific criteria where sufficient data are available.

Following the generation of the lower quartile values using each of the individual data points, a "trip" analysis was performed on mean total phosphorus values for lakes and impoundments to determine the relative proportion of waterbodies in a region that would likely exceed the lower quartile estimate. This analysis had been suggested by the PTW membership as a means of stating the degree of impact related to lower quartile-based water quality standards. A similar analysis had been performed in 1991 on a Bureau of Research dataset collected in 1979 in support of a statewide limnological survey of Wisconsin lakes. The key to this dataset was that the data were representative of a random collection of lakes and impoundments. This was in direct contrast to the STORET dataset, which is very reflective of "problem" waterbodies that, in many cases, were studied intensively by the WDNR in an effort to better manage those resources. Due to the random nature of the random lakes data and the fact that they did not necessarily represent "problem" waterbodies, lower quartile and trip analyses were performed on those data in an effort to compare them to the result of the STORET data analyses.

After reviewing the quartile and trip analysis data for both datasets (STORET and random lakes) the PTW agreed that the random lakes data should be used for any subsequent development of draft water quality criteria. The PTW did not want to totally abandon the STORET data, especially when the random lakes data were collected nearly 15 years earlier in 1979. Instead, the PTW membership agreed that a comparison of recently collected STORET data would be compared to the random lakes data to determine if water quality conditions had remained similar. More specifically, it was agreed that STORET data collected in a recent period of consecutive sample years would be analyzed to develop comparative quartiles. The "recent" dataset was to include all data collected in 1989-1993. No data collected in 1988 was to be included because it was a significant drought year. The resulting quartiles would be compared to those already generated for the random lakes dataset, and the PTW would review the comparison at a subsequent meeting. This exercise was begun, but it was found that there was a lack of data from lakes and impoundments that were the same between both datasets. The PTW made a decision not to compare the random dataset and recent STORET data because of this lack of data and also because of the conservativeness of the standards.

The PTW also agreed that impoundments should not be differentiated by drainage type because it is the nature of impoundments to have an outlet. All future standards development for impoundments should only consider the potential for thermal stratification in addition to the regional separation described earlier. The draft lake and impoundment criteria are as listed in Tables 1 and 2.

Table 1: Ambient Water Quality Criteria for Phosphorus in Natural Lakes (µg/L)

	Drainage/Mixed	Drainage/Stratified	Seepage/Mixed	Seepage/Stratified
North	15	10	10	10
Central	5	5	5	5
South	25	15	15	10

Table 2: Ambient Water Quality Criteria for Phosphorus in Impoundments (µg/L)

	Mixed	Stratified
North	15	10
Central	5	5
South	25	15

Recommendations to the Watershed Advisory Committee

After thorough review and discussion of the available scientific information on phosphorus and phosphorus-related impacts in lakes and impoundments, the PTW has concluded that meaningful stand-alone categorical statewide phosphorus water quality standards cannot be developed on a state or regional basis. The determination of whether lakes and impoundments have undesirable phosphorus-related impacts should ultimately be made on a site-specific basis, utilizing technical information and partner input. For this reason it is recommended that the numbers developed for use as water quality criteria be used as "triggers" or "flags" to require further action, if exceeded. The numbers were sent forward unlabeled (not criteria) for the Watershed Advisory Committee to determine the proper implementation methods.

The PTW endorses the use of a watershed-based regulatory approach that looks holistically at water quality within the watershed and utilizes partner involvement to prioritize and implement water quality initiatives within the watershed. With respect to phosphorus management, the PTW recommends use of an integrated approach that:

- Uses a screening step to identify those lakes and impoundments that may require a more thorough evaluation for phosphorus-related impacts.
- Establishes a formal evaluation process for these lakes and impoundments that may lead to the development of a site-specific or resource-specific standard, expressed as an in-stream phosphorus concentration, a total maximum daily load (TMDL), or some other appropriate measurement (e.g., chlorophyll *a* density).

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7. The Tennessee Valley Authority Reservoir Vital Signs Monitoring Program: Chlorophyll and Nutrients Rating Scheme

by Neil Carriker and Dennis Meinert, Tennessee Valley Authority

Philosophical Approach and Background

Algae are the base of the aquatic food chain; consequently, measuring algal biomass or primary productivity is important in evaluating ecological health. Without algae converting sunlight energy, carbon dioxide, and nutrients into oxygen and new plant material, a lake or reservoir could not support other aquatic life. Chlorophyll *a* is a simple, long-standing, and well-accepted measurement for estimating algal biomass, algal productivity, and trophic condition of a lake or reservoir (Carlson, 1977).

Developing appropriate expectations is critical to evaluating the implications of chlorophyll concentrations on reservoir ecological health. Generally, lower chlorophyll concentrations in the oligotrophic range are thought of as indicating good water quality conditions. Conversely, high chlorophyll concentrations are usually considered indicative of cultural eutrophication. However, these generalizations must be tempered by geologic and cultural considerations. The range of chlorophyll concentrations considered indicative of good, fair, and poor ecological conditions must be tailored to reflect knowledge of background or natural conditions within each watershed.

It is unrealistic to expect most Tennessee Valley reservoirs to have low chlorophyll concentrations because many are located in watersheds that have nutrient-rich, easily erodible soils. Most lakes and reservoirs in the Tennessee Valley naturally contain sufficient nutrients to support algal populations with chlorophyll concentrations in the mesotrophic range, even in the absence of anthropogenic sources and cultural eutrophication. However, two watersheds in the Tennessee Valley, the Little Tennessee River and the Hiwassee River watersheds, have soils (and consequently waters) with naturally low nutrient levels. The streams in these watersheds drain the Blue Ridge Ecoregion, which is largely characterized by thin soils and is underlain mostly with hard crystalline and metasedimentary rocks.

The classification scheme for evaluating chlorophyll concentrations in Tennessee Valley reservoirs is based on expected “natural” nutrient levels for each watershed. Professional judgment was used to identify concentration ranges indicative of good, fair, and poor conditions. This approach separates Tennessee Valley reservoirs into into two classes for chlorophyll expectations—those expected to be naturally oligotrophic because they are in watersheds with naturally low nutrient concentrations and those expected to be naturally mesotrophic. The reservoirs expected to be oligotrophic are in the Blue Ridge Ecoregion. This group includes Hiwassee, Chatuge, Nottely, Blue Ridge, and Parksville reservoirs in the Hiwassee River drainage; and Tellico and Fontana reservoirs in the Little Tennessee River drainage. The remainder, both mainstream Tennessee River reservoirs and reservoirs on tributaries to the Tennessee River, are expected to be mesotrophic.

The concentration ranges identified to represent good, fair, and poor conditions are much lower for reservoirs in the nutrient-poor watersheds. The primary concern for those reservoirs is early identification of cultural eutrophication. With early identification, appropriate actions can be taken to manage nutrient loadings and prevent shifts to higher trophic states. For the reservoirs expected to be mesotrophic, the principal concern is that algal productivity (and chlorophyll levels) not become too great because of the undesirable characteristics associated with eutrophic lakes (dense algal blooms, poor water clarity, low DOs, and predominance of noxious blue-green algae). For mesotrophic reservoirs where sufficient nutrients are available but chlorophyll concentrations remain low, some other factor such as excessive turbidity or toxicity usually is present that inhibits algal growth. Consequently, the rating for chlorophyll *a* is lowered when those conditions are observed.

Data Collection Methods

Depth-integrated composite chlorophyll *a* samples are collected monthly (April-October) from the photic zone (defined as twice the Secchi depth or 4 meters, whichever is greater). Concurrent algae and zooplankton samples are collected for screening and semi-qualitative examination of the plankton community assemblage. In addition, in-situ water column profiles of temperature, dissolved oxygen, pH, conductivity; and Secchi depth measurements are obtained each time samples are collected. Finally, on three of the monthly surveys (April, June, and August), the photic zone composite samples are analyzed for nutrient levels (total phosphorus, ammonia-nitrogen, nitrate+nitrite-nitrogen, and organic nitrogen) to help in evaluating the chlorophyll data and to help support trophic state assessments.

In 1996, physical/chemical water quality variables were measured at 33 locations on 19 Tennessee Valley reservoirs. Additional details on collection methods are available in an informal TVA report.

Chlorophyll Rating Scheme

Chlorophyll ratings at each sampling location are based on the average summer concentration of monthly, composite photic zone samples collected from April through October (or September). If nutrients are present (e.g., total phosphorus greater than 0.01 mg/L and nitrate+nitrite-nitrogen greater than 0.05 mg/L) but chlorophyll *a* concentrations are generally low (e.g., $< 3\mu g/L$), other limiting or inhibiting factors (e.g., high stream flows, turbidity, toxicity, etc.) are considered to be present, and the chlorophyll *a* rating is decreased one unit.

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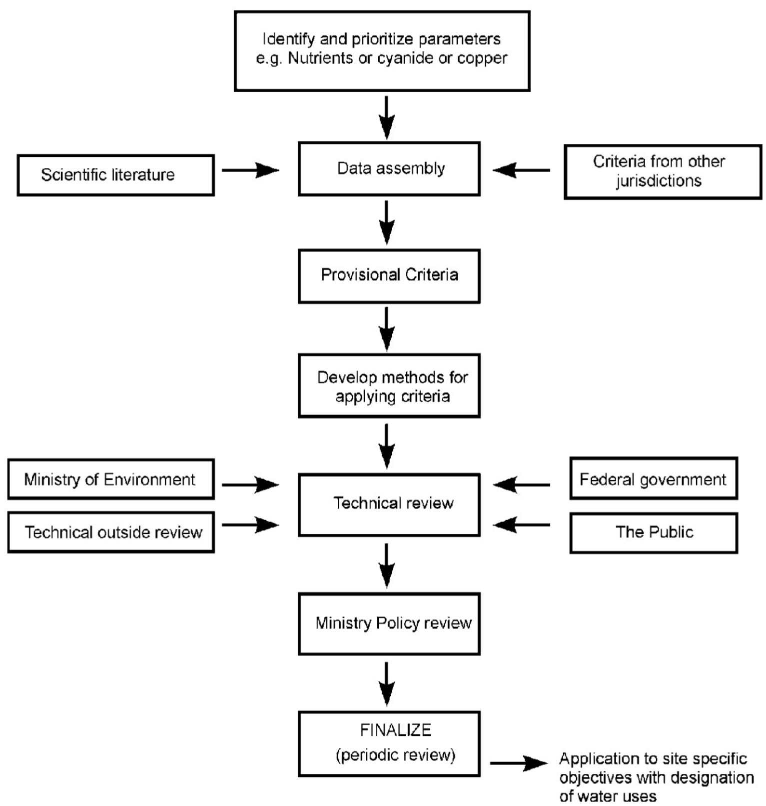
8. The British Columbia Water Use Based Approach

by Richard Nordin, British Columbia Ministry of the Environment

British Columbia has elected to establish criteria according to different uses (Nordin, 1986). In three of the water uses they have defined—drinking water, protection of aquatic life, and recreation and aesthetics—nutrients are important. The sequence for determining criteria is shown in Figure 1. Literature review, input from other agencies (e.g., existing criteria), and evaluation of problems that exist or have existed in British Columbia lakes were used to derive the criteria. The literature review focused on interrelationships between nutrients, primary productivity, and hypolimnetic oxygen

Figure 1: Sequence for Determining Water Quality Criteria



depletion; cold water fishery requirements; and public perception of water quality. British Columbia's criteria are presented in Table 1. Phosphorus concentration was used because there is ample evidence in the literature that quantitative interrelationships exist between it and chlorophyll and transparency, its acceptance as an index of eutrophication, and the advantage of quantifying the controlling parameter.

Nordin (1986) notes that these criteria are proposed specifically for British Columbia, where the lakes fall largely into the oligotrophic category and may not be directly applicable to other areas.

Criteria for lakes supporting warm-water fish were not included (Nordin, 1985). Nordin (1986) notes the difficulty in trying to establish criteria for lakes where a warm-water fishery is the most important use, stating that a phosphorus concentration below 10 µg/L is probably too low (leading to low fish productivity) and that concentrations up to 40 µg/L may be tolerable for lakes where recreational fisheries are important and conditions are suitable. The lack of either empirical or experimental data was cited as a major impediment to suggesting criteria for nutrient concentrations for fish or aquatic life other than the salmonid fishes (salmon and trout) that are of primary concern in British Columbia.

In applying these criteria and checking them against existing water quality, the water exchange time of the lake must be taken into account. The phosphorus concentration is measured at spring overturn (when the epilimnetic water residence time is greater than six months) or the mean epilimnetic growing season concentration is measured (if the epilimnetic residence time is less than six months).

The second step in the process is to apply the criteria to individual lakes. The criteria value may be modified up or down into an “objective” depending on the water uses or other circumstances that may apply for that specific lake. The various factors considered (i.e., data gathered) in establishing the objectives include hydrology, water uses, waste discharges, water quality data (including dissolved oxygen and temperature profiles, general chemistry nutrients, chlorophyll, and transparency),

Table 1: British Columbia’s Lake Water Quality Criteria for Nutrients

Most Sensitive Use	Phosphorus Criteria
Drinking water	<10 µg/L
Recreation and aesthetics	<10 µg/L
Aquatic life (cold-water fish)	5-15 µg/L*

*A range is suggested as the criterion that can be used as the basis for site-specific water quality objectives.

Source: Nordin, 1985.

phosphorus loading, algal species composition, and sediment chemistry. Details on the use of these factors may be found in Nordin (1985). The resulting water quality objectives by themselves have no legal standing and would not be directly enforced (McKean et al., 1987) but are used as a method for planning or for initiating other management techniques or administrative orders.

The objectives are considered policy guidelines for resource managers to protect water uses in the specified water bodies. They guide the evaluation of water quality; the issuing of permits, licenses, and orders; and the management of the fisheries and the province's land base. They will also provide a reference against which the water quality in a particular water body can be checked, and aid decisions on whether to initiate basin-wide water quality studies. In cases where objectives are set, the policy is to put into place a monitoring program for a period of at least three years to evaluate the lake to which the water quality objectives have been applied.

In some cases interim or intermediate goals for lake phosphorus concentrations have been used where ambient concentrations greatly exceeded the proposed criteria.

Uses of Lake Standards in British Columbia

British Columbia's phosphorus criteria serve as a tool for protecting the most sensitive lake uses. These uses typically include drinking, cold-water fish or other aquatic life, recreation, and aesthetics. The two primary applications of the criteria are:

- To evaluate data on water, sediment, and biota for water quality assessments.
- To establish site-specific water quality objectives.

Water quality objectives serve as policy guidelines for resource managers in their mission to protect water uses in specified water bodies. Water quality objectives guide the resource manager in the evaluation of water quality; issuance of permits, licenses, and orders; and management of fisheries and the watershed (McKean et al., 1987). They also provide a reference against which the water quality status in a particular water body can be monitored, and as a basis for making decisions on the initiation of basin-wide water quality studies. In many instances, the water quality objectives serve as the primary means of planning for the protection and evaluation of water quality (Ministry of Environment, 1985 and 1997).

The Ministry of Environment (1985) promotes the criteria as a means of avoiding the need for costly and high-precision loading studies. In contrast to accuracy needed to establish "critical" loadings in waste allocations, loading estimates in the context of water quality objectives are used only to determine relative contributions from various sources. The loading contribution estimates are then used to prioritize the importance of various inputs. In Okanagan Lake, where the water quality objective for the lake was the same as the 1985 phosphorus concentration (10 µg/L), the management strategy focused on maintaining concentrations (Ministry of Environment, 1985). In this case, if increased “trading” from development and municipal effluent were to occur, then reductions from the sources (e.g., agricultural sources or septic tanks) would need to be sought. This suggests that point/nonpoint source “trading” is among British Columbia's management tools to ensure that water quality objectives are met.

Specific water quality objectives have been set in about 15 lakes where the entire objective setting (rigorous evaluation) has been done. The criteria have been applied to evaluating hundreds of other lakes.

In some of the lakes in the province where long-term eutrophication problems exist and where phosphorus concentrations greatly exceeded the criteria (several lakes with phosphorus concentrations greater than 50 µg/L), the objectives were either set to the criteria (5 to 15 µg/L) or an interim goal (30 µg/L) (Wood Lake in Ministry of Environment, 1985 or Charlie Lake in Nordin and Pommen, 1985).

The most recent approach has been to combine the phosphorus objectives with biological objectives that specify phytoplankton community composition where, for instance, reduction in the frequency or numbers of cyanobacteria is a goal for water quality protection (Cavanagh et al., 1994).

Overall the approach to using a water-use-based approach has been well accepted within British Columbia and is also used by the Canadian federal government in specifying its criteria for a variety of water quality parameters.

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9. Rationale for a Revised Phosphorus Criterion for Precambrian Shield Lakes in Ontario

by Neil Hutchinson, Ontario Ministry of Environment and Energy

The Ontario Ministry of Environment and Energy (OMEE) manages environmental quality primarily through two pieces of provincial legislation, the Environmental Protection Act and the Ontario Water Resources Act. Policies and procedures for management of surface water quality that arise from this legislation are elaborated in implementation documents such as *Water Management: Policies, Guidelines, Provincial Water Quality Objectives of the Ministry of Environment and Energy (1994)* (OMEE, 1994).

The goal of surface water management in Ontario is:

> *"to ensure that the surface waters of the province are of a quality which is satisfactory for aquatic life and recreation."*

Ontario established Provincial Water Quality Objectives (PWQOs) in the 1970s in order to meet this goal. The first objectives were mostly adopted from other agencies, such as the International Joint Commission, but were later developed in Ontario (OMEE, 1992).

> "PWQOs are numerical and narrative ambient surface water quality criteria. They are applicable to all waters of the province (e.g., lakes, rivers, and streams) except in those areas influenced by OMEE approved point source discharges. In specific instances where groundwater is discharged to surface waters, PWQOs may also be applied to the groundwater. PWQOs represent a desirable level of water quality that the OMEE strives to maintain in the surface waters of the province. In accordance with the goals and policies in Water Management (OMEE, 1994), PWQOs are set at a level of water quality which is protective of all forms of aquatic life and all aspects of the aquatic life cycle during indefinite exposure to the water. The objectives for protection of recreational water uses are based on public health and aesthetic considerations" (MOEE, 1994).

Two policies are used to interpret the water management goal and application of the PWQOs to specific water bodies (MOEE, 1994).

- *Policy 1*

  "In areas which have water quality better than the Provincial Water Quality Objectives, water quality shall be maintained at or above the Objectives. Although some lowering of water quality is permissible in these areas, degradation below the Provincial Water Quality Objectives will not be allowed, ensuring continuing protection of aquatic communities and recreational uses."

- *Policy 2*

  "Water quality which presently does not meet the Provincial Water Quality Objectives shall not be further degraded and all practical measures shall be taken to upgrade the water quality to the Objectives."

Ontario's PWQO development process was developed specifically to deal with toxic substances. It uses published studies on the effects of pollutants to estimate a safe concentration for indefinite exposure. The only data that are mandatory for PWQO development are data on toxicity, bioaccumulation, and mutagenicity (MOEE, 1992), but the process does permit the development of a PWQO based upon aesthetic impairment, such as taste or odor. If insufficient data are not available a "guideline" or "interim objective" status is assigned to the resultant water quality criterion.

Existing PWQO for Total Phosphorus

The existing PWQO for total phosphorus was developed in the late 1970s (OMEE, 1979). It drew on the trophic status classification scheme of Dillon and Rigler (1975) to protect against aesthetic deterioration and nuisance concentrations of algae in lakes and excessive plant growth in rivers and streams. The rationale (OMEE, 1979) acknowledges that elemental phosphorus can be toxic, but that it is rare in nature and so toxicity is rarely of concern. (In fact, there is only one documented case of elemental phosphorus poisoning an aquatic [marine] system in Canada). Instead, the purpose of the objective was to protect the aquatic ecosystem non-toxic forms of phosphorus :

> *"phosphorus must be controlled, however, to prevent any undesirable changes in the aquatic ecosystem due to increased algal growth...."* (OMEE, 1979).

The 1979 PWQO was given the status of a "guideline" both to reflect the uncertainty regarding the effects of phosphorus and to acknowledge the difference between managing toxic and non-toxic pollutants.

> *"Current scientific evidence is insufficient to develop a firm objective at this time. Accordingly, the following phosphorus concentrations should be considered as general guidelines which should be supplemented by site-specific studies:*
>
> - *To avoid nuisance concentrations of algae in lakes, average total phosphorus concentrations for the ice-free period should not exceed 20 µg/L.*
> - *A high level of protection against aesthetic deterioration will be provided by a total phosphorus concentration for the ice-free period of 10 µg/L or less. This should apply to all lakes naturally below this value.*
> - *Excessive plant growth in rivers and streams should be eliminated at a total phosphorus concentration below 30 µg/L."*

The Need For Revision

Although the 20 intervening years have shown that the phosphorus guideline is sound, more recent science has revealed new concerns that were not addressed in the original. In 1996, therefore, Ontario decided to review its PWQO for total phosphorus. The bulk of Ontario's 226,000 lakes (Cox, 1978) lie on the Precambrian Shield, and the scientific basis for a new PWQO had previously been developed for these lakes (Hutchinson et al., 1991). Accordingly, the three-year review process targetted Precambrian Shield lakes first, with off-shield lakes, the Great Lakes, and streams and rivers reviewed later in the process.

The rationale for revisiting the PWQO for phosphorus does not lie exclusively in better information on the effects of phosphorous as a pollutant. Instead, better understanding of watershed processes, biodiversity, and cumulative impact assessment over the past 20 years led to the corporate adoption of these considerations in the water management process (OMEE, 1994). This knowledge revealed several shortcomings with the existing, two-tiered guideline of 10 µg/L for "a high level of protection against aesthetic deterioration" and 20 µg/L "to avoid nuisance concentrations of algae." Although these numeric objectives are designed to maintain water clarity and aesthetic values and have performed well for over 20 years, they fall short in the area of protecting the diversity of the provincial resource of water quality and any associated biodiversity.

Trophic Status Considerations

The existing numeric objectives for total phosphorus ignore fundamental differences between lake types and their nutrient status in the absence of human impact. Ontario's Precambrian Shield lakes presently span a range of phosphorus concentrations ranging from oligo to mesotrophic, and all are represented in roughly equivalent proportions in the provincial lake resource (Figure 1). Within this range, however, there is still a large diversity of water clarity, controlled by both total phosphorus concentrations and dissolved organic carbon (Dillon et al., 1986).

The logical outcome of a two-tiered objective is that, over time, all recreational waters would converge on one or the other of the water quality objectives. This would produce a cluster of lakes slightly below 10 µg/L and another slightly below 20 µg/L, decreasing the provincial diversity in water quality in lakes and, with it, lower diversity of their associated aquatic communities.

The second shortcoming is that, over time, some lakes would sustain unacceptable changes in water quality while others would be unimpacted, producing both ecological and economic asymmetries as the resource was developed. A lake with a natural phosphorus concentration of 4 ug/L is a fundamentally different lake from one that exists at 9 µg/L. Both lakes, however, would be allowed to increase to 10 µg/L under the existing PWQO. One lake would experience no perceptible change (9 - 10 µg/L) and be overprotected, but the other (4 - 10 µg/L) would be underprotected and change dramatically. In both cases, human perceptions of aesthetics are ignored in the objective. Allocation of phosphorus loadings between these two lakes would be unfair as well. The higher-phosphorus lake could sustain a greater change than the low-phosphorus lake but would be restrained to a much lower load.

A final concern is that the existing PWQO does not explicitly consider the impact of phosphorus on hypolimnetic oxygen or aquatic biota. It does, however, make reference to site-specific studies in the assessment process.

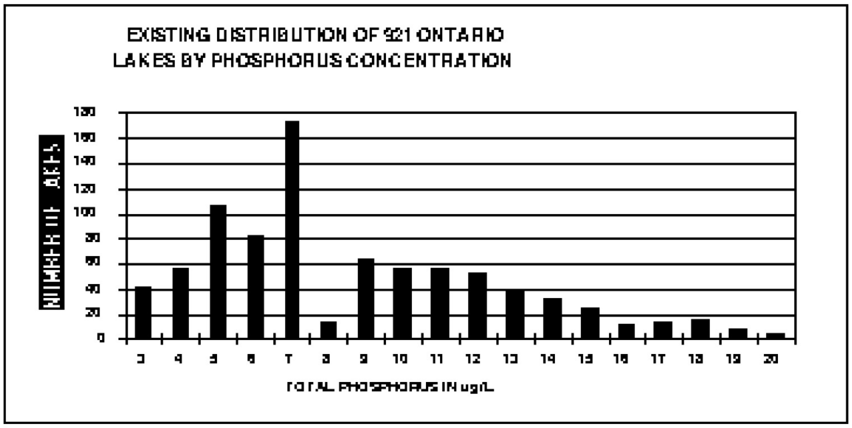
In summary, the existing numeric objectives overprotect some lakes and do not protect others adequately. Allocation of phosphorus loadings is unnecessarily restricted in some lakes and overly generous in others. Neither biotic nor aesthetic attributes are adequately protected. Over time the diversity of trophic status that is presently represented in Ontario will decrease.

Environmental Baselines and Measured Water Quality

An emerging concern in environmental assessment is the need for a standard baseline for comparison against environmental change. Inland lakes respond quickly to point-source phosphorus inputs. Detection of change is much more difficult, however, for non-point sources such as leachate from domestic septic systems.

Existing approvals and interpretation of the existing PWQO are based on measurements of water quality. Measurements of phosphorous made in the period between development of a shoreline and expression of change in trophic status, however, will significantly underestimate its impact and may wrongfully conclude that the lake has not responded to phosphorus loading.

Figure 1: Existing Distribution of 921 Ontario lakes by Phosphorus Concentration



The incremental nature of shoreline development (no lake is ever developed all at once) results in a slow and gradual increase in trophic status. The high degree of seasonal and annual variance in phosphorus levels in lakes (Hutchinson and Clark, 1992) means that changes may not be detectable without an intensive monitoring program, based on many samples and a precise and replicable analytical method.

Finally, a slow increase in trophic status over a generation may not be noticed by human observers. Environmental change that occurs over one generation becomes the status quo for the next. Over a long period, therefore, any assessment baseline that is based on measurements of total phosphorus will increase.

Any phosphorus objective that relies exclusively on measured water quality will therefore suffer from:

- Detection problems due to natural variance and analytical problems
- The lag time between addition of phosphorus to a watershed and its expression in a lake
- Failure to detect incremental changes in water quality
- Human perceptual conditioning that reduces the apparent change in water quality over time

As a result, an increasing assessment baseline and incremental increases in water quality will slowly degrade water quality past any objective. Impacts will accumulate by virtue of delay in their expression, repetition over time and space, extension of the impact boundary by downstream transport, or by triggering indirect changes in the system, such as anoxic sediment release. Non-point source phosphorus pollution, particularly from septic systems serving shoreline development, is thus an excellent example of a pollutant that produces cumulative impacts to the aquatic environment. The emergence and validation of mass balance phosphorus models for lakes, however, offers an opportunity to correct some of the disadvantages of water quality measurements and conventional assessment techniques.

Total Phosphorus and the PWQO Development Process

Development of a PWQO for total phosphorus is distinctly different from that for toxic substances. It is therefore inappropriate to adhere strictly to the established procedures (MOEE, 1992). Because phosphorus is not toxic, insufficient scientific evidence on its toxicity should not be the rationale for its guideline status. Instead, guideline status should reflect the subjectivity inherent in managing a non-toxic pollutant.

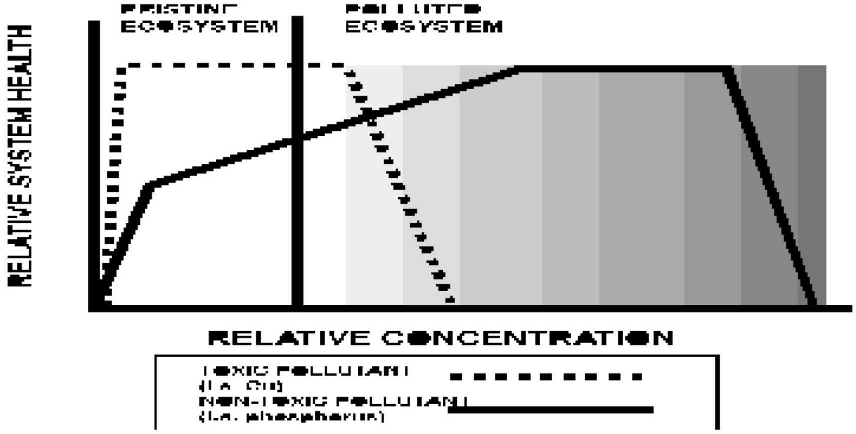
Most pollutants are directly toxic to some target tissue, such as the fish gill, even if some of them are required nutrients at trace amounts, i.e., copper or zinc. As a result, the health of aquatic organisms, and hence the ecosystem, declines rapidly at concentrations slightly above ambient levels (Figure 2). Phosphorus, on the other hand, is a major nutrient. Concentrations can increase substantially with no direct toxic effects. In fact, the first response of the aquatic system is increased productivity and biomass. Beyond a certain point, however, indirect detrimental effects become apparent, which ultimately decrease system health.

Because phosphorus is not toxic, it is used as a surrogate for attributes such as water clarity or dissolved oxygen that we wish to protect. The first responses of a lake to enrichment (i.e., water clarity, algal blooms) are aesthetic and of concern only to humans. Assessment of aesthetic impacts is highly subjective; perceived changes in water clarity are based largely on what one is used to (Smeltzer and Heiskary, 1990). The development of a phosphorus objective must therefore acknowledge an element of subjectivity in dealing with human concerns. The objective-development process may also consider that aesthetic impacts begin where a change in water clarity is first noticeable to the human eye, or where the mean water clarity first exceeds natural variation.

Biotic impacts of phosphorus enrichment, such as the loss of oxygenated hypolimnetic habitat for cold water species (i.e., lake trout [*Salvelinus namaycush*]) are known and can be addressed objectively (Maclean et al., 1990) . Dissolved oxygen concentrations are explicitly protected by the Ontario PWQO for Dissolved Oxygen (MOEE, 1994) and are not intended as a direct consideration in phosphorus objective development. Nevertheless, recent advances in oxygen-phosphorus models (i.e., Molot et al., 1992) allow direct estimation of the impact of phosphorus concentrations on dissolved oxygen in lakes. Any protection of dissolved oxygen that is achieved, even indirectly, by the phosphorus objective is beneficial, and its consideration prevents the possibility of one PWQO inadvertently contradicting another.

Finally, trophic status indicators such as water clarity, chlorophyll *a*, or dissolved oxygen cannot be managed directly, but only through management of phosphorus. In addition, there may be delays of up to decades between the addition of phosphorus sources to a watershed (i.e., septic systems), its movement from the source to surface water (Robertson, 1995) and its expression as a change in trophic status. Shoreline residential development represents a significant contribution to eutrophication of Ontario's Precambrian Shield lakes (Dillon et al., 1986). As a result, phosphorus management in Ontario requires the extensive use of models relating shoreline development to the trophic status of the receiving water. Phosphorus management may therefore be considered as a process of "predicting the predictor."

Figure 2: Generalized responses of an ecosystem to toxic and non-toxic pollutants



Proposal for a Revised PWQO

Recent advances in phosphorus modeling, understanding of watershed dynamics, and cumulative impact assessment have been used to propose a new PWQO for Ontario's Precambrian Shield lakes. The proposal encompasses two innovations: the use of models to establish a baseline for changes in trophic status and a proportional increase from that baseline due to anthropogernic phosphorus loadings. The challenge now lies in expanding this understanding beyond shoreline development in Precambrian Shield lakes, for which it was originally developed, to apply it to all the waters of the province, including off-shield lakes and the Great Lakes, rivers, and streams.

Modeled assessment baseline

The basis of the revised PWQO is increased reliance on water quality modeling in the objective-setting process. Recent advances in trophic status models allow us to calculate the "pre-development" phosphorus concentrations of inland lakes (Hutchinson et al., 1991). This is done by modeling the total phosphorus budget for the lake, comparing the predicted concentration to a reliable water quality measurement, and subtracting that portion of the budget attributable to human activities. Further work is necessary for water bodies lying off of the Precambrian Shield, but the basic premise is applicable to any water body where a phosphorus budget can be calculated.

The main advantage of the modeling approach is establishment of a constant assessment baseline. A modeled "predevelopment" baseline is based on an undeveloped watershed and so will not change over time. This serves as the starting point for all future assessments. Every generation of water quality managers will therefore have the same starting point for their decisions, instead of a steadily increasing baseline of phosphorus measurements.

We therefore propose a PWQO for total phosphorus that is based on a modeled "predevelopment" phosphorus concentration. This will provide water quality managers with:

- A constant assessment baseline,
- A buffer against incremental loss of water quality, and
- A buffer against variable water quality measurements.

The predevelopment phosphorus concentration should not be interpreted as a PWQO. Pristine phosphorus levels have not existed in Ontario for over a century and their attainment is not cost-effective in a heavily developed society. The modeled predevelopment concentration only serves as the starting point for the PWQO and a reference point for future changes.

A model-based objective would have two additional advantages. First, the modeled response of the watershed to future changes is instantaneous. It applies new development directly against capacity, without the intervening decades it takes for phosphorus to move to a lake and be expressed as a measured change in water quality. Second, Ontario's trophic status model is based on entire watersheds and so allows explicit consideration of downstream phosphorus transport in the assessment.

Proportional Increase

The second component of the objective is a proportional increase from the modeled predevelopment condition. The proportional increase accomodates regional variation in natural or "background" water quality through the use of one numeric objective for all Precambrian Shield lakes. It is, in fact, a broader, yet simpler, application of the regionally specific, multi-tiered objectives proposed in other jurisdictions as a means of accommodating regional variation in background water quality (i.e., Minnesota—see Heiskary, this volume, and Wisconsin—see Searle, this volume).

Ontario is proposing an allowable increase of 50% above the predevelopment level from anthropogenic phosphorus sources. Under this proposal, a lake that was modeled to a predevelopment phosphorus concentration of 4 µg/L would be allowed to increase to 6 µg/L. Predevelopment concentrations of 6, 10, or 12 µg/L would increase to 9, 15, or 18 µg/L, respectively. A cap at 20 ug/L would still be maintained to protect against nuisance algal blooms.

There are numerous advantages to this approach:

- Each water body would have its own water quality objective, but this could be described with one number (i.e., predevelopment plus 50%).
- Development capacity would be proportional to a lake's original trophic status.
- As a result, each lake would maintain its original trophic status classification. A 4 µg/L lake would be developed to 6 ug/L and therefore maintain its distinction as oligotrophic. A 9 µg/L lake would be developed to 13.5 µg/L, would maintain its trophic status, and development would not be unnecessarily constrained to 10 µg/L.
- The existing diversity of trophic status in Ontario would be maintained, instead of a set of lakes at 10 µg/L and another at 20 µg/L.

Rationale for 50% Increase

Water Clarity

Water clarity in Ontario's Precambrian Shield lakes is controlled by both dissolved organic carbon (DOC) and phosphorus (Dillon et al., 1986). Any phosphorus objective should therefore consider DOC as well as phosphorus in its derivation. Molot and Dillon (pers. comm.) used 14 years (1976-1990) of data from lakes in south-central Ontario to produce the following relationship, summarized in Figure 3.

$$SD = 6.723 - (0.964 \times DOC) + (9.267/TPep)$$

Figure 4 shows the response of water clarity to various proportional increases in total phosphorus concentration, predicted for various DOC levels using the same equation. Responses are grouped to include all lakes with initial phosphorus concentrations between 2 and 14 ug/L, and so a 50% increase represents final values of 3 to 21 ug/L. There is no clear threshold of changed water clarity, a point where further increases in phosphorus would induce a markedly more severe change in water clarity. Instead, Figure 3 shows a gradual loss of water clarity as phosphorus concentrations are increased from 10% to 100%. The allowable percentage increase cannot, therefore, be determined on the basis of water clarity alone.

Detection of Change in Phosphorus and Water Clarity

The average coefficient of variation in Secchi depth for a series of Southern Ontario Precambrian Shield lakes was 17%-21% over a 14-year period of record (Clark and Hutchinson, 1992). A change of 25% in water clarity would therefore represent a significant departure from natural variation and be detectable against it. A 50% increase in phosphorus concentration produces an average 25% loss of Secchi depth across the range of initial phosphorus (2-14 µg/L) and DOC (2-7) shown in Figure 3 and Table 1. In addition, a 50% increase protects the clearest and most desirable water clarity and allows a greater proportional change only in those lakes with high DOC where water clarity is limited by DOC instead of by the phosphorus/chlorophyll relationship (Table 1).

Figure 3: Relationship of Predicted Water Quality to Total Phosphorus and DOC Concentrations in Precambrian Shield Lakes in South-Central Ontario

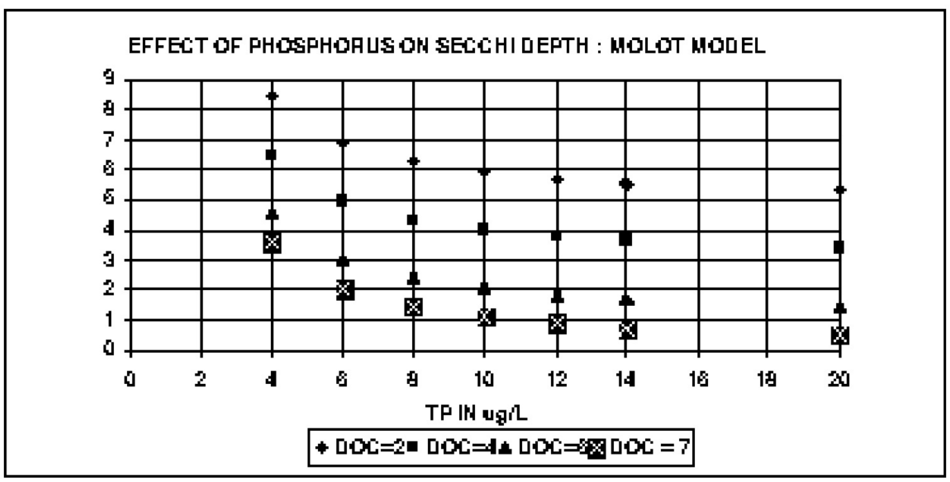


Figure 4: Predicted Response of Secchi Depth in 10-100% Increases in Phosphorus Concentration From Initial Values of 2-14 µg/L

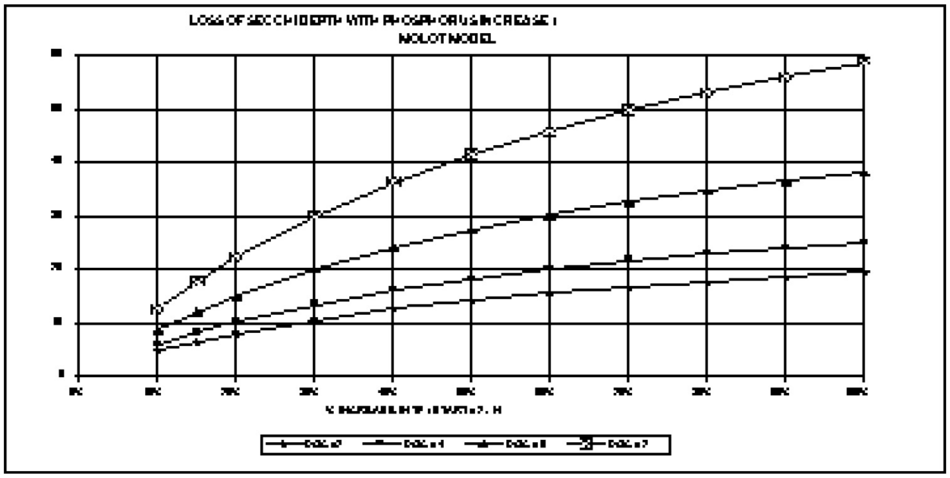


Table 1: Average loss of Secchi depth with a 50% increase in total phosphorus concentration as a function of dissolved organic carbon concentration

	DOC=2	DOC=4	DOC=6	DOC=7	Average
% loss of clarity	14	18	27	41	25.3

Note: The 50% increase in TP is taken from a starting range of 2-14 µg/L to produce final values of 3-21 µg/L.

Hutchinson et al. (1991) reported a natural coeffcient of variation in total phosphorus concentrations in South-Central Ontario lakes of about 20%. Detection of a 20% change in total phosphorus requires only 2 years of spring overturn measurements or 1 year of 4-5 measurements in the ice-free season (Clark and Hutchinson, 1992). A phosphorus objective 50% greater than the predevelopment conditions would therefore be detectable with even the most rudimentary sampling program and would limit changes in water clarity to an average of 25%, a level just beyond the range in natural variation of Secchi depth.

Protection of Dissolved Oxygen

Dissolved oxygen concentrations are explicitly protected by the Ontario PWQO for Dissolved Oxygen. The existing PWQO for D.O. is 6 mg/L at 10ºC for cold-water (stratified) lakes (OMEE, 1994). This marks the upper limit of typical hypolimnetic water temperature, and represents the optimum for the production of lake trout, an esteemed cold-water species in Ontario (Maclean et al., 1990). Although dissolved oxygen concentrations are not intended as a direct consideration in phosphorus objective development, any protection achieved, even indirectly, by the phosphorus objective is beneficial, and its consideration prevents the possibility of one PWQO inadvertently contradicting another. Oxygen-phosphorus models can be used for direct estimation of the impact of phosphorus on dissolved oxygen in lakes.

The Molot et al. (1992) model predicts the hypolimnetic oxygen profile at the critical end-of-summer period, when lakes are warmest and oxygen depletion is near maximum. It was used to model the impact of a 50% increase in phosphorus on dissolved oxygen (Hutchinson, 1997, unpubl.). Four stratified lake types were modeled, spanning a range from highly sensitive (shallow and small) to least sensitive (deep and large). Responses were expressed as volume-weighted average hypolimnetic oxygen concentration and as the volume of hypolimnion exceeding the PWQO of 6 mg/L.

On average, a 50% increase in phosphorus protects dissolved oxygen in any lake that is larger than 67 ha and 28m or deeper and has less than 12 µg/L of predevelopment phosphorus. Some portion of the hypolimnion remained at 6 mg/L of D.O. or better in all such lakes modeled. Lakes with predevelopment concentrations of 7 µg/L or less were particularly well protected but the 50% increase did not protect lakes that were naturally at 12 µg/L TP or greater, because of their higher initial phosphorus concentrations.

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10. Dillon Reservoir Phosphorus Standard, Load Allocation, and Crediting System

by Robert Ray, Northwest Colorado Council of Governments

Dillon Reservoir is located in Summit County, Colorado, at an elevation of 9,000 feet. Constructed in 1963 as Denver's primary water supply, the reservoir holds 254,000 acre feet of water and has a surface area of 3,300 acres. Dillon Reservoir has also become a recreational center for fishing, camping, and boating. One of the reservoir's main attractions is its reputation for clear, deep blue water.

During the late 1970's and early 1980's, Summit County was one of the fastest growing areas of the country. About this time, water quality degradation in the reservoir became apparent with the onset of algal blooms. A "Clean Lakes" study identified phosphorus as the limiting factor for algal growth in the reservoir. Studies of phosphorus loading to the reservoir revealed that approximately one-half of the phosphorus load came form natural sources, while the other half was from human activities including municipal wastewater effluent, parking lot runoff, construction site runoff, seepage from septic systems, and other nonpoint sources (Elmore et al., 1985).

A stakeholder committee (the Summit County Phosphorus Policy Committee) was established to develop a strategy for protection of water quality in the reservoir. The Committee included representatives from the towns, the county, the sanitation districts, the Denver Water Department, a ski area, and a mining company. The newly formed Committee established a goal of maintaining the 1982 water quality in Dillon Reservoir. This corresponded to an in-lake phosphorus concentration of 7.4 µg/l during the algal growing season of July through October, adjusted to 1982 hydrologic conditions. Based on this goal, a control regulation was established by the State's Water Quality Control Commission in 1984, which included an in-lake phosphorus standard, a wasteload allocation, and language acknowledging local land use regulations for the control of nonpoint source phosphorus loads.

The four municipal wastewater dischargers to the reservoir installed advanced treatment equipment to control phosphorus, and the wasteload allocation was developed based on build-out projection flows and a phosphorus effluent concentration of 0.2 mg/l (the plants are currently discharging less than 0.05 mg/l phosphorus).

The phosphorus standard served as the numerical basis for back-calculating the necessary load reductions to achieve the desired conditions at zoned "build-out" of the basin. The overall strategy requires a "2 for 1" credit between nonpoint source phosphorus reductions and point source wasteload allocation increases, effective erosion and sediment control practices, mitigation for increases in nonpoint source phosphorus loading from new development, and the use of CDPS (Colorado Discharge Permit System) permits for enforcement if necessary.

There have been three approved applications for phosphorus credits to wasteload allocations to date. It is likely that the main reason that more projects for phosphorus credits have not occurred is the fairly large buffer between the wastewater treatment plants' existing annual loads and their wasteload allocations. The buffer was created by the extremely efficient operations of the wastewater treatment plants.

The reservoir continues to be monitored by the Summit Water Quality Committee (SWQC), which is funded by its participants - the towns, county, and sanitation districts. The SWQC has developed a Phosphorus Accounting System, which was developed to address the concern that the model developed as part of the Clean Lakes study continues to project that at "build out" of the basin, phosphorus loads will exceed the in-lake standard. The County is using its land use authority to require pound-for-pound mitigation of increased phosphorus loads from increases in zoning density during the Planned Unit Development process.

The reservoir continues to meet its phosphorus standard and chlorophyll *a* goal.

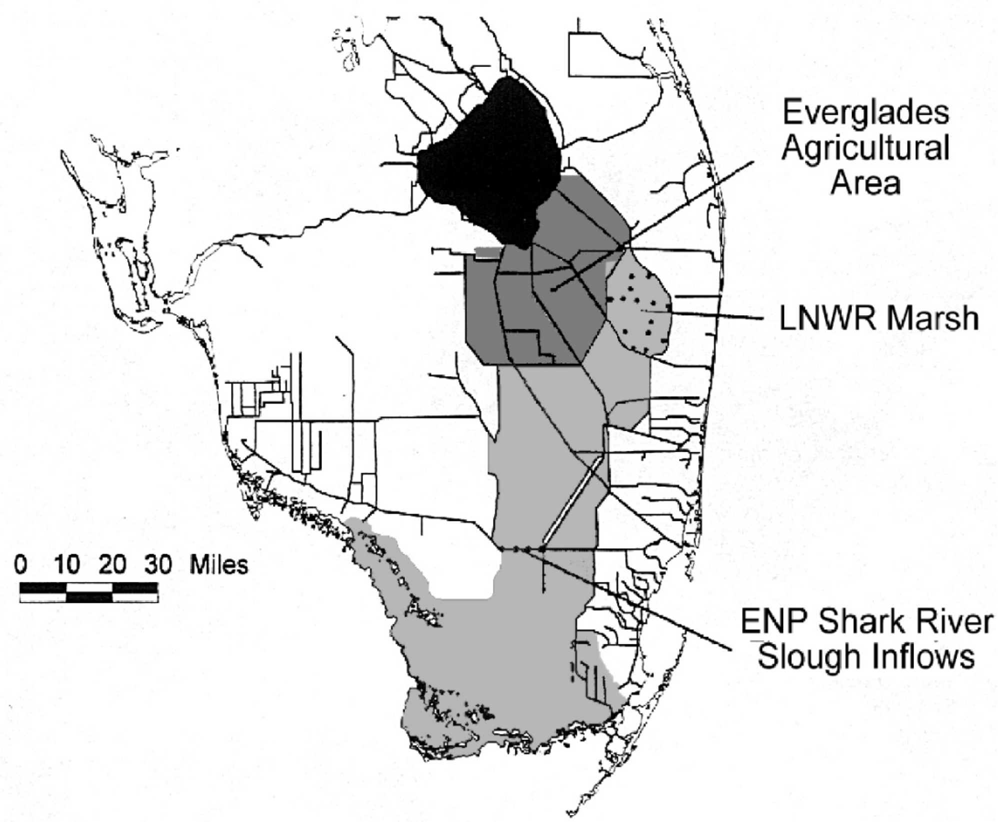
11. Interim Phosphorus Standards for the Everglades

by William W. Walker, Jr.

Eutrophication induced by anthropogenic phosphorus loads poses a long-term threat to Everglades ecosystems. Substantial shifts in macrophyte and microbial communities have been observed in regions located downstream of agricultural discharges (Belanger et al., 1989; Nearhoof, 1992; Davis, 1994). This problem developed over a period of three decades following construction of the Central and Southern Florida Flood Control Project and drainage of wetland areas south of Lake Okeechobee to support intensive agriculture (Figure 1).

In 1988, a lawsuit was filed by the federal government against the local regulatory agencies (Florida Department of Environmental Regulation and South Florida Water Management District (SFWMD)) for not enforcing water quality standards in Loxahatchee National Wildlife Refuge (LNWR) and Everglades National Park (ENP). The lawsuit ended in an out-of-court Settlement Agreement (SA) (USA et al., 1991) and federal consent decree in 1992.

Figure 1: Projects in South Florida



The SA establishes interim and long-term requirements for water quality, control technology, and research. Generally, interim standards and controls are designed based upon existing data and known technologies The interim control program includes implementation of agricultural Best Management Practices (BMP's) and construction of wetland Stormwater Treatment Areas (STA's) to reduce phosphorus loads from the Everglades Agricultural Area (EAA) by approximately 80 percent, relative to a 1979-1988 baseline.

Subsequently, SFWMD adopted the EAA Regulatory Rule (SFWMD, 1992; Whalen and Whalen, 1994), which requires implementation of BMP's in the EAA to achieve an annual-average phosphorus load reduction of at least 25 percent. The State of Florida (1994) passed the Everglades Forever Act, which defines a construction project and funding mechanism for STA's. Interim phosphorus standards will apply after interim control technologies are in place (1999-2006 for LNWR and 2003-2006 for ENP Shark Slough Inflows). Long-term standards (>2006) and control technologies will be developed over a period of several years and require a substantial research effort to develop supporting data.

Specific statistical procedures for tracking progress of the restoration effort and for determining compliance with interim and long-term objectives are built into the Settlement Agreement, EAA Regulatory Rule, and Everglades Forever Act. These procedures provide measures of performance that are important from technical, political, and legal perspectives. This report describes the general model upon which these procedures are based. Specific applications include:

- P standards for inflows to ENP (2 basins)
- P standards for marsh stations in LNWR
- Load-reduction requirements for the EAA

Each tracking procedure was developed within the constraints of historical data to accomplish a specific objective. They share a model structure which is generally applicable in situations where historical monitoring data are to be used as a frame of reference for interpreting current and/or future monitoring data. This would be the case when the management goal is to restore the system to its historical condition, to prevent degradation beyond its current condition, or to require improvement relative to its historical or current condition. This paper describes the model and its application to ENP Shark River Slough inflows. Other applications are briefly summarized.

General Model

Explicit consideration of variability is the key to formulating a valid tracking procedure. Procedures are developed by calibrating the following general model to historical data:

Response = Average + Temporal Effect + Hydrologic Effect + Random Effect (1)

The Response is the measurement to be tracked (e.g., concentration or load, averaged over appropriate spatial and temporal scales, linear or log-transformed). The Average represents the mean value of the Response during the calibration period. The Temporal Effect represents a long-term trend in the historical data (if present); this may reflect anthropogenic influences (e.g., land development, new point-source discharges, etc.). The Hydrologic Effect represents correlations of the Response with other measured variables, such as flow, water level, and/or rainfall (if present). The Random Effect is essentially an error term which represents all other sources of variance, including sampling error, analytical error, and variance sources not reflected in the Temporal or Hydrologic terms.

As demonstrated below, inclusion of Temporal and Hydrologic terms increases the statistical power of the tracking procedure (reduces risk of Type I and Type II errors). These terms can be excluded in situations where long-term trends are not present or where significant correlations between the response variable and hydrologic variables cannot be identified. In such a situation, the response would be treated as a purely random variable and the model would be identical to that described by Smeltzer et al. (1989)

for tracking long-term variations in lake water quality. The model can be expanded to include multiple Hydrologic Effects, interactions between Temporal and Hydrologic Effects, as well as other deterministic terms. Seasonal Effects (if present) can be considered by adding another term or eliminated by defining the Response as an annual statistic (average, median, etc.).

The model is not constrained to any particular mathematical form. For example, Hydrologic Effects can be predicted by a simulation model, provided that uncertainty associated with such predictions (Random Effects) can be quantified. The applications described below invoke relatively simple, multiple regression models which provide direct estimates of parameter uncertainty. The Hydrologic term provides a basis for adjusting historical and future monitoring data back to an average hydrologic condition, so that changes in the long-term mean (typically reflecting anthropogenic influences) can be tracked and not confused with random climatologic variability (e.g., wet-year vs dry-year differences).

Table 1 outlines three applications of the model to the Everglades. Data from a consistent, long-term monitoring program are desirable for calibrating and applying the model. Ideal data sets are rarely encountered, however, particularly if historical monitoring programs were not designed explicitly to collect data for this purpose. Everglades applications are based upon data sets ranging from 7 to 11 years in duration with monitoring frequencies ranging from biweekly to monthly. One strength of the data is that sampling and analyses have been consistently performed by a single agency (SFWMD). The following sections describe calibration and application of the model to ENP Shark River Slough inflows.

Model Calibration to Historical Monitoring Data

Interim standards for ENP Shark River Slough were designed to provide annual, flow-weighted-mean concentrations equivalent to those measured between March 1, 1978, and March 1, 1979, the legally established base period consistent with ENP's designation as an Outstanding Florida Water (OFW). Analysis of monitoring data collected between December 1977 and September 1989 collected at five inflow structures (S12A,B,C,D & S333) revealed significant increasing trends in phosphorus concentrations and negative correlations between concentration and flow (Walker, 1991). To reduce possible influences of season and shifts in the flow distribution across the five inflow structures, the annual-average, flow-weighted-mean concentration across all five structures was selected as a response variable and basis for the interim standard. Annual values for Water Years 1978-1990 (October-September) were used to calibrate a regression model of the following form:

$$Y = Ym + b_1 (T - Tm) + b2 (Q - Qm) + E \qquad (2)$$

where

Y = observed annual, flow-weighted-mean concentration (ppb)
T = water year (1978-1990)
Q = basin total flow (1000 acre-ft/yr)
E = random error term
m = subscript denoting average value of Y, T, or Q in calibration period

Prior to calibration, biweekly concentration data used to calculate annual flow-weighted means were screened for outliers from a log-normal distribution while accounting for correlations between concentration and flow (Snedocor & Cochran, 1989); a single sample was rejected on this basis. Data from Water Years 1985 and 1986 were excluded from the calibration because of unusual operating conditions which promoted discharge of high-phosphorus canal flows (vs. marsh sheet flows) through the inflow structures. The flow-weighted-mean concentrations were 33 and 21 ppb, respectively, as compared with a range of 7 to 18 in other Water Years. These unusual operating conditions are not expected to be repeated in the future.

Table 1: Model applications to the Everglades

Location	**Everglades Agricultural Area**	**ENP Shark Slough Inflows**	**Loxahatchee National Wildlife Refuge**
Reference	EAA Regulatory Rule (1992) Whalen & Whalen (1994)	Interim Standards Settlement Agreement (1991)	Interim Standards Settlement Agreement (1991)
Objective	25% Load Reduction vs. Oct 1979-Sept 1988	1978-79 conditions; baseline period for outstanding Florida waters	1978-79 conditions; baseline period for outstanding Florida waters
Response variable	Total P load	Total P concentration	Total P concentration
Temporal averaging	May-April water year	Flow-weighted mean Sept-Oct water year	Monthly
Spatial averaging	Total EAA thru 18 structures, adjusted for inputs from other basins & releases from Lake Okeechobee	Combined inflows from 5 structures in Shark River slough	Geometric mean across 14 marsh stations
Calibration period	May 1979-April 1988 9 water years 2058 samples	Oct 1977-Sept 1990 11 water years 222 sampling dates 1115 samples	July 1978-July 1983 14 sampling rounds 191 samples
Samples excluded	3 statistical outliers	Oct 1984-Sept 1986 (2 water years, unusual operation) 1 statistical outlier	2 dates with mean stage < 15.42 ft (missing values; marsh sampling difficult)
Temporal effect	None	Linear trend	Step change after base period
Hydrologic effect(s)	Basin rainfall, 9 stations Thiessen average Rainfall statistics: annual total, CV of monthly totals, skewness of monthly totals	Basin total flow Total thru 5 structures	Stage (water surface elev) Average of 3 stations
Transformation	Natural logarithm	None	Natural logarithm
Variance explained	90%	80%	67%
Residual standard error	0.18 (~18%)	1.87 ppb (~16%)	0.31 (~31%)
Base period	Water years 1980-88	Water years 1978-79	June 1978-May 1979 First full year of data
Target	75% of base period (25% load reduction)	100% of base period	100% of base period
Limit	90th percentile	90th percentile	90th percentile
Exceedence condition	> limit in any year, or > target in ≥ 3 consecutive years	> limit in any year	> limit in > 1 month in any consecutive 12-month period

Table 2 lists calibration data and results. The model explains 80% of the variance in the historical data set with a residual standard error of 1.87 ppb. The fit is illustrated in Figure 2. Figure 2A plots observed and predicted concentrations against time. The 80 percent prediction interval (10th, 50th, and 90th percentiles) are shown in relation to the observed data. Both regression slopes are significant at $p < .05$. The partial regression concept (Snedocor & Cochran, 1989) is applied below to illustrate the importance of each term in the model.

Table 2: Derivation of interim standards for ENP Shark River Slough inflows

		Flow-Weighted-Mean Total P Concentration					
Water year	Basin Flow kac-ft/yr	Observed ppb	Predicted ppb	Flow-Adjusted ppb	Detrended ppb	50% target ppb	90% limit ppb
78	522.8	6.7	8.4	6.7	7.0	8.4	11.7
79	407.0	9.8	9.6	9.2	9.5	9.0	12.3
80	649.2	10.6	9.0	11.2	9.7	9.6	11.1
81	291.7	12.4	11.3	11.4	11.0	10.2	12.9
82	861.3	8.4	9.2	10.0	6.3	10.8	10.1
83	1061.3	7.0	8.9	9.5	4.4	11.4	9.4
84	842.8	12.0	10.5	13.4	8.7	12.0	10.2
87	276.6	15.9	14.9	14.8	10.9	13.8	13.0
88	585.5	15.6	14.1	15.9	10.0	14.4	11.4
89	116.9	13.5	16.9	11.6	7.3	15.0	14.0
90	148.2	18.1	17.3	16.3	11.2	15.6	13.8
Mean	523.9	11.8	11.8	11.8	8.7	8.7	11.8

Variables: Y = observed TP (ppb), T = water year, b_1,b_2 = regression slopes, m = subscript denoting mean value, Q = observed flow (kac-ft/yr), E = random error (ppb), SE = regression standard error of estimate (ppb), m = subscript denoting mean value..

Regression model: $Y = Y_m = b_1(T - T_m) + b_2 (Q - Q_m) + E$

$= 11.8 + 0.5932 (T - 83.7) - 0.00465 (Q - 523.9) + E$

Regression results: $R^2 = 0.80$, SE = 1.873 ppb, $Y_m = 11.8$ ppb, $T_m = 83.7$, $Q_m = 523.9$ kac-ft/yr, $b_1 = 0.5932$, $Var(b_1) = 0.02366$, $b_2 = -0.00465$, $Var(b_2) = -0.0046$, $Cov(b_1,b_2) = 0.00013$, $t_{,dof} = 1.397$, $n = 11$.

Y_Q = Flow-adjusted TP = $Y + b_2 (Q_m - Q) = Y - 0.00465 (523.9 - Q)$

Y_T = Detrended TP = $Y + b_1 (T_o - T) = Y + 0.5932 (78.5 - T)$

Target = $Y_m + b_1 (78.5 - T_m) + b_2 (Q - Q_m) = 11.16 - 0.00465 Q$

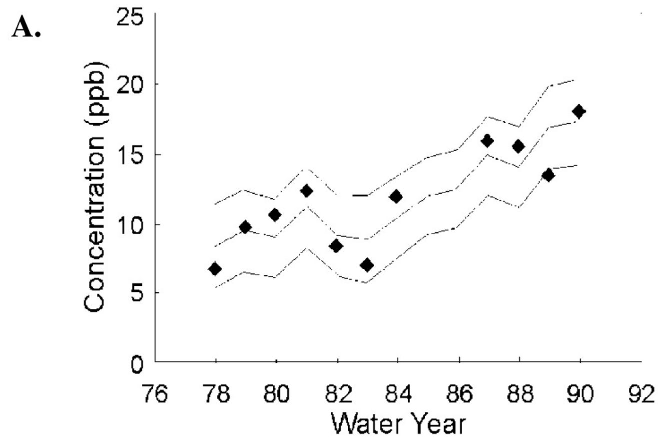
Limit = Target + $S\ t_{,dof} = 11.16 - 0.00465 Q + 1.397 S$

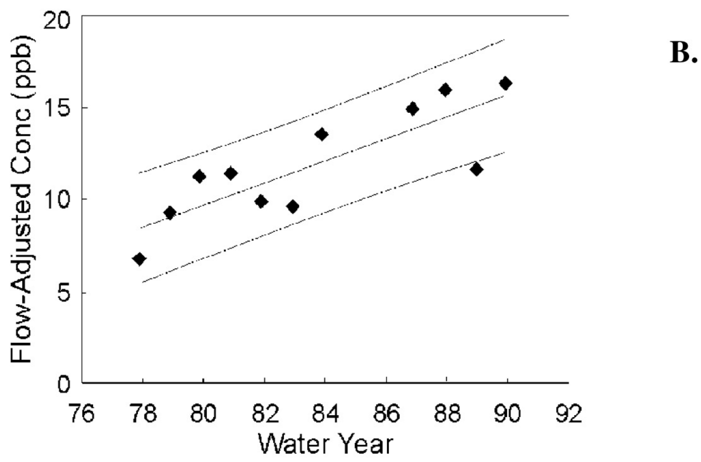
$S = [SE^2 (1 + 1/n) + Var(b_1) (T_o - T_m)^2 + Var(b_2) (Q_c - Q_m)^2 + 2 Cov(b_1,b_2) (78.5 - T_m)(Q_c - Q_m)]0.5$

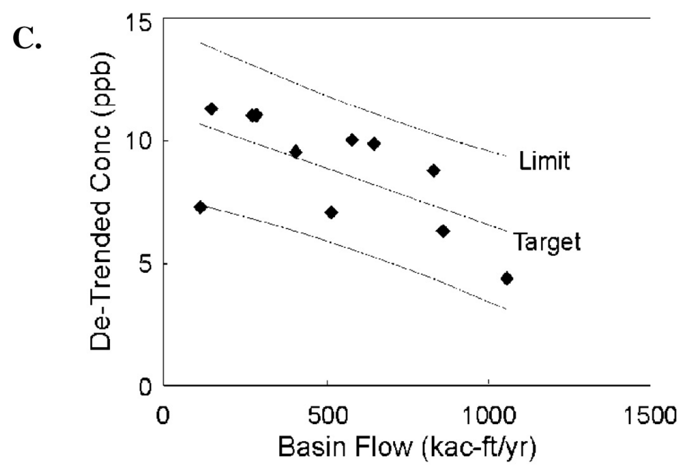
$= [6.377 - 0.00591 Q + 0.00000436 Q^2]^{0.5}$

Figure 2: Model calibration to ENP Shark River Slough inflows

Legend:
Symbols = Observed Flow-Weighted Means
Lines = 80% Prediction Intervals
A = Observed
B = Adjusted to Mean Flow
C = Adjusted to 1978-1979 Conditions;
October - September Water Years.







The concentration measured in any year (Y) can be adjusted back to an average flow condition (Qm) using the following equation for flow-adjusted concentration (YQ):

$$YQ = Y + b_2 \, (Qm - Q) \qquad (3)$$

Figure 2B plots observed and predicted flow-adjusted concentrations against time. The long-term trend is more readily apparent in this display because effects of flow variations have been filtered out.

Similarly, the concentration in any year can be adjusted back to any base period (To) using the following equation for a time-adjusted or de-trended concentration (YT):

$$YT = Y + b_1 \, (To - T) \qquad (4)$$

In this case, a base period value of To = 78.5 is used to represent the 1978-1979 OFW time frame. Using this equation, Figure 2C plots observed and predicted time-adjusted concentrations against flow. The inverse correlation between concentration and flow is apparent. The figure shows the predicted relationship between concentration and flow if long-term mean were equivalent to that experienced in 1978-1979.

The model can be used to evaluate the likelihood that current monitoring results (Yc, Qc) are equivalent to the 1978-1979 base period, while accounting for hydrologic and random variability. This is accomplished using the following terms which characterize the prediction interval for a 1978-1979 time frame under a given flow condition:

$$Target = Ym + b_1 \, (To - Tm) + b_2 \, (Qc - Qm) \qquad (5)$$

$$Limit = Target + S \; t \, ,dof \qquad (6)$$

$$S = [\; SE2 \; (1 + 1/n) + Var(b_1) \; (To - Tm)2 + Var(b_2) \; (Qc - Qm)2$$
$$+ \; 2 \; Cov(b_1,b_2) \; (78.5 - Tm)(Qc - Qm) \;].5 \qquad (7)$$

where

Target = 50th Percentile of Prediction Interval = Predicted Mean (ppb)
Limit = 90th Percentile of Prediction Interval (ppb)
S = Standard Error of Predicted Value (ppb)
SE = Regression Standard Error of Estimate (ppb)
t = One-tailed Student's t statistic
Significance Level = 0.10
dof = Degrees of Freedom = n - 3
n=Number of Years in Calibration Data Set = 11
Var = Variance Operator
Cov = Covariance Operator

In Figure 2C, the Target and Limit lines correspond to the 50th and 90th percentile predictions, respectively. The required parameter estimates and variance/covariance terms are derived from a standard multiple regression analysis. If the current long-term flow-weighted-mean is less than the 1978-1979 long-term mean (adjusted for hydrologic effects), there would be less than a 50 percent chance that the yearly mean (Yc) would exceed the Target and less than a 10 percent chance that Yc would exceed the Limit. The difference between the Target and Limit reflects the magnitude of the Random Effects term and uncertainty in model parameter estimates (b_1, b_2, Ym).

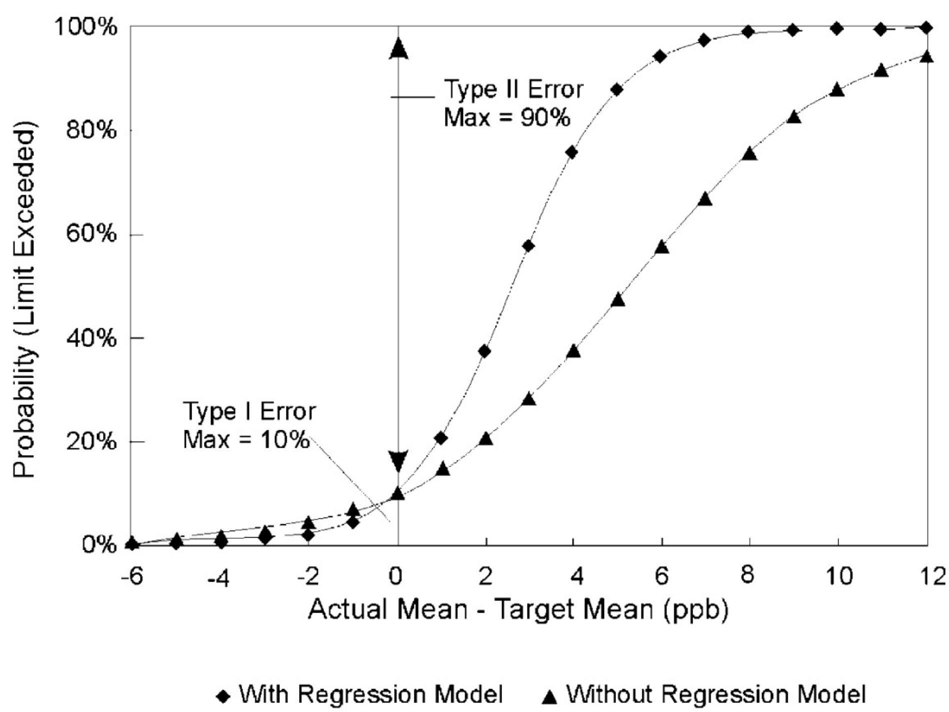
Type I and Type II Errors

Under the terms of the Settlement Agreement, an exceedence of the Limit in any year would trigger further scientific investigations which, in turn, may lead to implementation of additional phosphorus control measures. The significance level for the compliance test (.10) represents the maximum Type-I error rate (probability of exceeding the Limit if the future and 1978-1979 long-term means are exactly equal). Unless a model can be constructed to explain all of the variance in the data, there is no way to design a compliance test without explicitly adopting a maximum Type-I error. In this case, the .10 value was arrived at by negotiation and with the understanding that results of the test would be interpreted by a scientific panel in light of the inherent risk of Type I error.

Type II error (failure to detect an exceedence or excursion from the standard) is another unavoidable feature of compliance tests. In this case, a Type II error would occur when the actual long-term mean exceeds the 1978-1979 flow-adjusted mean but the measured annual mean is still below the Limit. Risk of Type II error depends upon the specified maximum Type I error (10%), model error variance (Random Effects Term), and the magnitude of the excursion from the long-term mean.

Figure 3 illustrates Type I and Type II error concepts. The probability that the annual mean exceeds the Limit is plotted against the difference between the actual long-term mean and the target. Probabilities are calculated using standard statistical procedures (Snedecor and Cochran, 1989; Walker, 1989). Type I errors (false exceedence) may occur when the actual long-term mean is below the target. The risk of Type I error equals the probability shown on the left-hand side in Figure 4 and has maximum value of 10 percent (by design). Type II errors (failure to detect exceedence) may occur when the actual mean exceeds the target. The risk of Type II error equals 100 percent minus the probability shown on the right-hand side of Figure 4 and has a maximum value of 90 percent. As deviation from the target increases, risks of Type I and Type II errors decrease.

Figure 3: Type I and Type II errors



Probability curves are shown for two values of residual standard error in Figure 3. Without applying the regression model, the Random Effects term in the model would have a standard deviation of 3.73 ppb (= standard deviation of annual flow-weighted-means in the calibration period). With the regression model, the standard deviation is reduced to 1.87 ppb. Removing variance associated with trend and flow increases the probability of exceeding the Limit when the long-term mean exceeds the target. For example, if the true long-term mean were 5 ppb above the target, the probability of detecting an excursion (measured annual value above Limit) would be ~90 percent with the regression model, but only ~50 percent without the regression model. Risk of Type I error when the actual mean is below the target is also lower with the regression model. The regression approach thus enables a more powerful compliance test than would result from treating the calibration data set as a random time series.

Model Application to Recent Monitoring Data

Figure 4 shows monitoring results for the Water Years 1991-1996 (6 years following the 1978-1990 calibration period). Although interim standards will not be enforced until 2003, the procedure is useful for tracking responses to control measures implemented over the 1991-2002 period. Such measures include adoption of the EAA Regulatory Rule (requiring a 25% reduction in EAA phosphorus load) in 1992 and operation of the Everglades Nutrient Removal Project (ENR, pilot scale STA removing an additional ~9% percdent of the EAA phosphorus load) (Guardo et al., 1995; SFMWD, 1997) starting in August 1994.

Figure 4A shows observed values before and after the calibration period in relation to the 80% prediction interval derived from the above regression model. Values in Figure 4A reflect both long-term trend and flow variations. Observed values in 1992-1996 fall near the lower boundary of the 80% prediction interval (10th percentile).

Figure 4B shows flow-adjusted concentrations (equation 3) in relation to the 80% prediction interval. The prediction interval extrapolates the increasing trend in the 1978-1990 data to the later years. Theoretically, flow-related variations are filtered from this time series, so that observed and predicted values reflect variations in the long-term mean. The plot suggests that the increasing trend present during the calibration period has been arrested in recent years.

Figure 4C plots concentrations against flow in relation to the 80 percent prediction interval for 1978-1979 conditions. Observed values during the 1978-1991 calibration period have been adjusted to the 1978-1979 time frame (equation 4). The middle and upper values in the prediction interval correspond to the Target and Limit values at any flow. Compliance with the interim standards (when they are in effect) will require that the observed (unadjusted) flow-weighted mean fall below the Limit line in every year.

Discussion

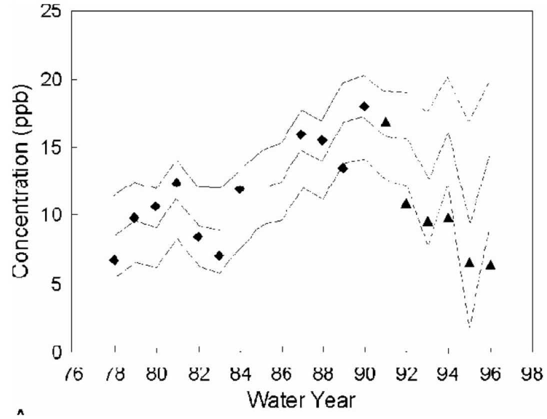
Extremely wet conditions experienced in recent years relative to the calibration period impose significant limitations on tracking results. Figure 5 plots annual basin flow against time. Flow exceeded the maximum value experienced in the base period (1061 kac-ft/yr) in 3 out of 6 Water Years after 1990. In these cases, the model is being extrapolated beyond the range of the calibration data set. The extrapolation is particularly large in Water Year 1995, when the average flow exceeded the calibration maximum by approximately 2.5-fold. Because of the extrapolation into high flow regimes, the model does not provide reliable assessments in recent wet years. Nonetheless, the model does provide the best currently available scientific assessment of long-term trends in phosphorus at these structures.

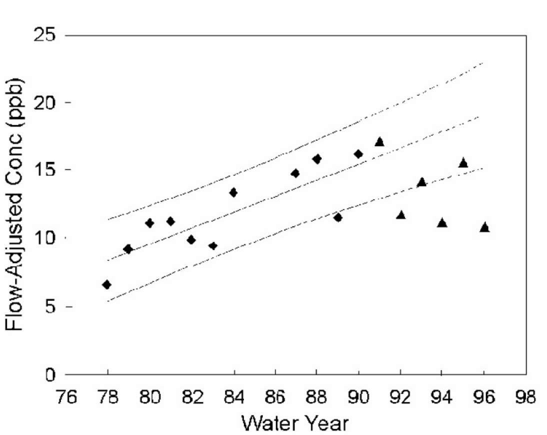
Figure 4B suggests that the increasing trend in the long-term mean present prior to 1991 has been arrested in years following adoption of the EAA Regulatory Rule in 1992 and operation of the ENR in 1994. For the 6-year period between May 1992 and April 1997, the tracking procedure for EAA phosphorus load (Table 1) indicates an average load reduction of 46% relative to the May 1979-April

Figure 4: Model Application to ENP Shark River Slough Inflows

Legend:

Diamonds	=	Observed Flow-Weighted Means, Calibration Period (1978-1990)
Triangles	=	Observed Flow-Weighted Means (1991-1996)
Lines	=	80% Prediction Intervals
A	=	Observed
B	=	Adjusted to Mean Flow
C	=	Adjusted to 1978-1979 Conditions (Calibration Period), Observed (1992-1996) Oct. - Sept. Water Years.





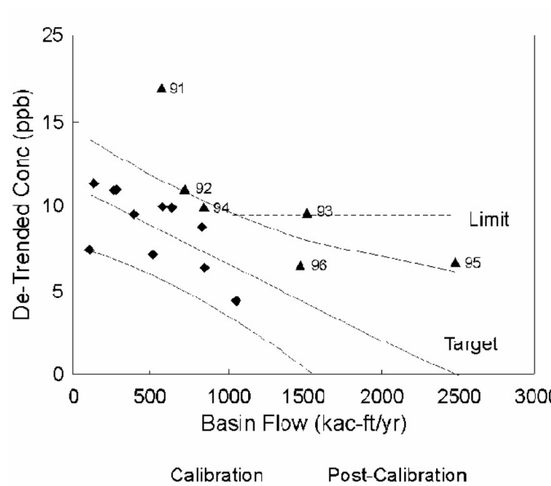
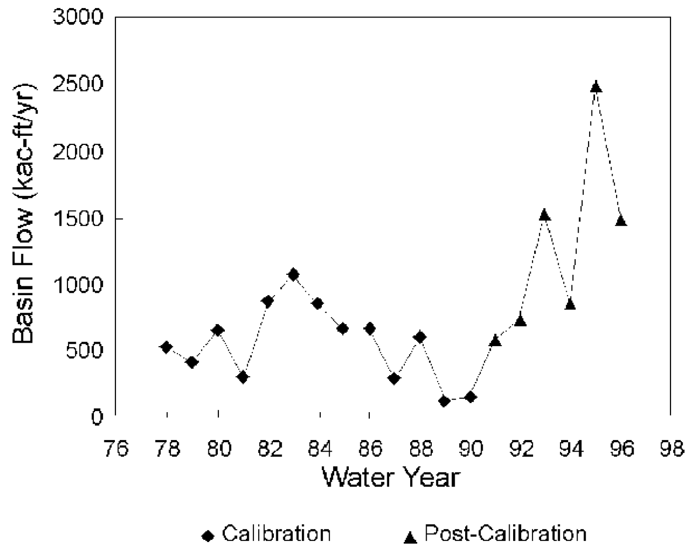


Figure 5. Flow variations.



Legend: Diamonds = calibration period (1978-1990); triangles = after calibration period (1991-1996); horizontal line = maximum flow in calibration period Oct-Sept water years.

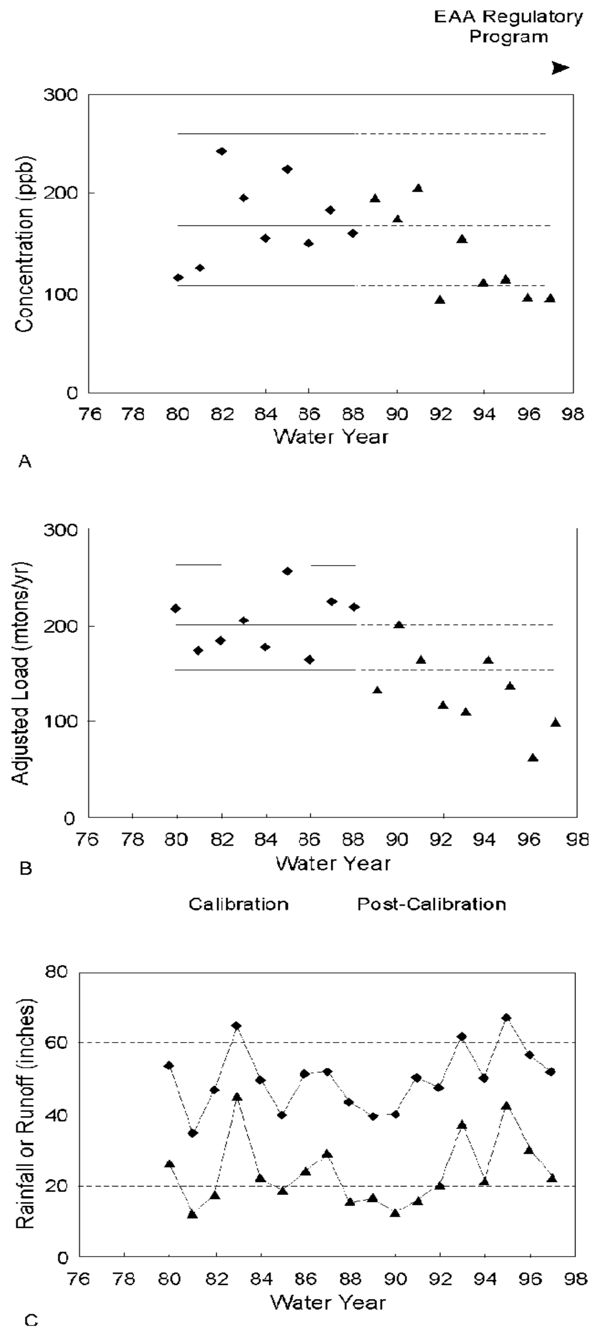
1988 base period for the Rule and adjusted for variations in rainfall. Figure 6 shows annual variations in phosphorus concentration and adjusted load from the EAA. Compared with the model discussed above, the model for tracking EAA phosphorus loads is calibrated to a slightly different base period and employs a different Water Year definition (May-April). A regression against rainfall statistics (Table 1) is used to adjust measured loads to average hydrologic conditions during the base period. The accuracy of EAA adjusted load estimates is also limited by wet conditions experienced in recent years, however.

EAA runoff concentrations are not adjusted because they are weakly correlated with rainfall. Prediction intervals for concentration are derived by assuming that the Random-Effects term of the model follows a log-normal distribution calibrated to base-period results.

Other possible factors contributing to water quality improvements at ENP inflows during recent wet years include (1) increased phosphorus retention under high-stage conditions in the Water Conservation Areas and (2) shifts in the distribution of flow across the Tamiami Trail. A higher percentage of flow is released through the S12's (western) as opposed to S333 (eastern) in wet years because of flow-control constraints in the Eastern Everglades. Historically, P concentrations at S333 have been higher than those at measured at the S12's, because flows passing through S333 contain a higher percentage of canal flow (vs. marsh sheet flow). Because of limitations in the tracking methodology during recent wet years, several years of monitoring under average and dry conditions will provide a more reliable assessment of ENP inflow water quality conditions in relation to the 1978-1979 OFW period.

Despite signs of improvement, it is unlikely that the interim control objective for ENP Shark Slough inflows has been achieved, since the flow-adjusted means in recent years are consistently above the 1978-1979 flow-adjusted mean (~ 8 ppb, Figures 2B, 4B). Observed concentrations in 1992-1996 cluster

Figure 6. Variations in EAA runoff P concentratin and adjusted load



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Legend: Diamonds = calibration period (1980-88); triangles = after calibration period (1989-97); lines = 80% prediction intervals; A = flow-weighted-mean total P concentration; B = total P load, adjusted for variations in rainfall; C = average rainfall and runoff..   May-April water years.

around the Limit line in Figure 4C. If the interim objectives were achieved, the observed values would be expected to cluster around the Target line (center of distribution).

Under the provisions of the Settlement Agreement, the maximum flow during the calibration period (1061 kac-ft/yr) will be used to calculate the Limit in years when the observed flow exceeds that value. This essentially prevents extrapolation of the regression beyond the calibration range. The dashed line in Figure 3C shows the Limit calculated according to this procedure. One could argue whether this procedure provides a better estimate of the 90th percentile at high flows than the extrapolated (solid) line. The distribution of observed values after 1991 is such that the determination of "compliance" (if the standard were in effect) would be influenced only in the case of the extreme high-flow year (1995). In the remaining years, the system would have been in compliance in 2 out of 5 years (1994 and 1996), regardless of which limit line is used.

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12. Total Phosphorus Criteria for Lake Champlain

by Eric Smeltzer, Vermont Department of Environmental Conservation

Lake Champlain is a 170 km long natural lake shared by the States of Vermont and New York and the Province of Quebec, with a basin population of over 600,000. The major use of the lake is for recreation, although the lake also serves as a water supply for 180,000 people. There are 88 point source phosphorus discharges in the Lake Champlain Basin, although nonpoint sources represent over 70% of the total phosphorus loading to the lake (Smeltzer and Quinn, 1996). Total phosphorus concentrations vary spatially within Lake Champlain over a range of 9-58 µg/L.

Total phosphorus concentration criteria have been established for 13 segments of Lake Champlain in the Vermont Water Quality Standards and in a New York, Quebec, and Vermont Water Quality Agreement for Lake Champlain. The phosphorus criteria were derived in part from an analysis of lake user survey data. The user survey analysis established quantitative relationships between total phosphorus concentrations and the frequency of aesthetic problems and recreational use impairments caused by algae. The criteria were used to guide a process involving phosphorus load measurements and mass balance modeling that resulted in a phosphorus reduction agreement and basin plan completed in accordance with the federal Lake Champlain Special Designation Act of 1990. Allowable phosphorus loads were established for each sub-watershed in Vermont, New York, and Quebec in order to attain the in-lake phosphorus criteria.

User Survey Analysis and Derivation of the Criteria

Lake user surveys have been used in Vermont, Minnesota, and elsewhere to identify specific total phosphorus, chlorophyll a, or Secchi disk values at which algal nuisances and impairment of recreation are perceived by the public (Heiskary and Walker, 1988; Smeltzer and Heiskary, 1990; North American Lake Management Society, 1992). The user survey form used in Lake Champlain from 1987-1991 as part of a citizen volunteer water quality monitoring program is shown in Table 1. The first survey question (A) asked the observers to describe the physical condition of the lake water at the time samples were taken. The second question (B) sought an opinion on the recreational suitability of the lake at the time of sampling. The survey responses were accompanied by simultaneous water quality measurements using standard sampling and analytical procedures employed by the Vermont Lay Monitoring Program (Picotte, 1997).

The results from the five years of user survey data in Lake Champlain included over 900 individual observations distributed among 28 lake stations in which citizen monitors completed the survey form at the same time measurements were made of total phosphorus, chlorophyll-a, and Secchi disk depth. The results are illustrated in Figure 1.

Figure 1 shows the transitions that occur in lake user perceptions and enjoyment as the degree of eutrophication increases in Lake Champlain. Where total phosphorus and chlorophyll-a concentrations are low, and transparency high, few observers indicate that they see high algae levels or find their enjoyment of the lake substantially reduced by algae in the water. However, as phosphorus and

Table 1. User Survey Form Used in Lake Champlain from 1987 to 1991

A. Please circle the one number that best describes the physical conditions of the lake water today.

1. Crystal clear water.
2. Not quite crystal clear, a little algae.
3. Definite algal greenness, yellowness, or brownness apparent.
4. High algal levels with limited clarity and/or mild odor apparent.
5. Severely high algae levels with one or more of the following: massive floating scums on lake or washed up on shore, strong foul odor, or fish kill.

B. Please circle the one number that best describes your opinion on how suitable the lake water is for recreation and aesthetic enjoyment today.

1. Beautiful, could not be any nicer.
2. Very minor aesthetic problems; excellent for swimming, boating, enjoyment.
3. Swimming and aesthetic enjoyment slightly impaired because of algae levels.
4. Desire to swim and level of enjoyment of the lake substantially reduced because of algae levels.
5. Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels.

chlorophyll levels increase and transparency declines, indications of obvious algal greenness in the water, and impairment of lake use, become more frequent responses.

The results shown in Figure 1 were used to quantify the instantaneous phosphorus levels at which critical transitions in user perceptions occur in Lake Champlain. User descriptions such as "a little algae" and "very minor problems" predominate when total phosphorus concentrations are below about 25 µg/L. Above the 25 to 30 µg/L phosphorus interval, responses such as "definite algal greenness" and "use slightly impaired" are most commonly noted. More severe nuisance perceptions involving "high algae levels" and "enjoyment substantially reduced" also begin to become frequent as phosphorus levels increase above 25 µg/L. These results suggested that an instantaneous total phosphorus concentration of 25 µg/L could be used to derive eutrophication criteria values for Lake Champlain.

Lake eutrophication criteria are best expressed as season or annual mean values, rather than as instantaneous "not to exceed" values. Means are estimated with greater statistical stability by monitoring programs and are more readily predicted by lake models (Walker, 1985; North American Lake Management Society, 1992). An analysis of within-season temporal frequency distributions for total phosphorus in Lake Champlain was used to define a summer mean value corresponding to an appropriately low frequency of occurrence of the 25 µg/L instantaneous nuisance criterion, using Walker's (1985) statistical algorithm. Simple nonparametric tabulation approaches have also been used for this purpose (Heiskary and Walker, 1988).

The relationship between the summer station-mean total phosphorus concentration and the frequency of values greater than 25 µg/L recorded at Lake Champlain monitoring stations is shown in Figure 2. Figure 2 was used to derive a mean phosphorus criterion of 14 µg/L, representing a value at which the 25 µg/L nuisance value would be exceeded only 1% of the time during the summer.

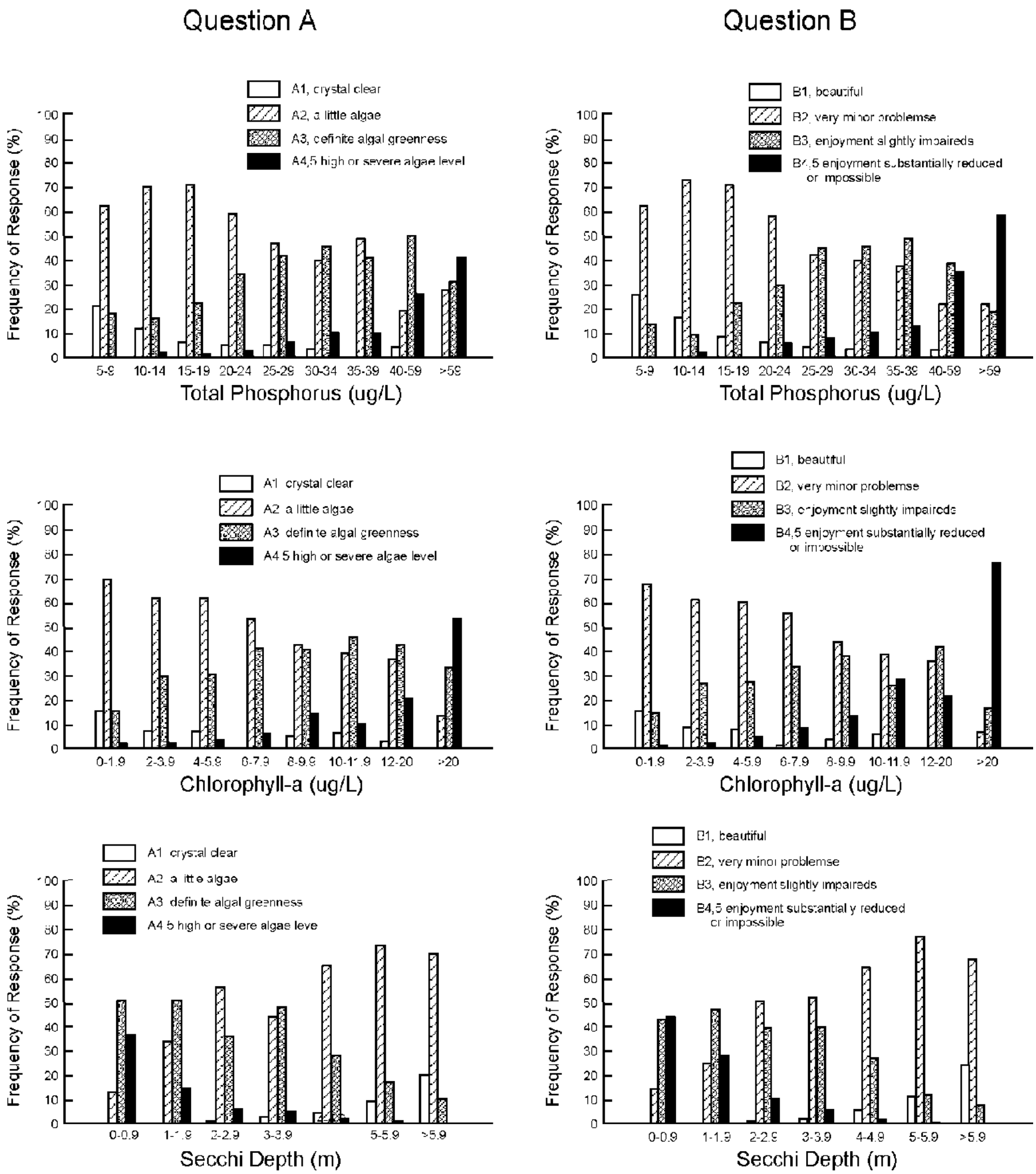

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Figure 1. Lake Champlain user survey results, 1987-1991

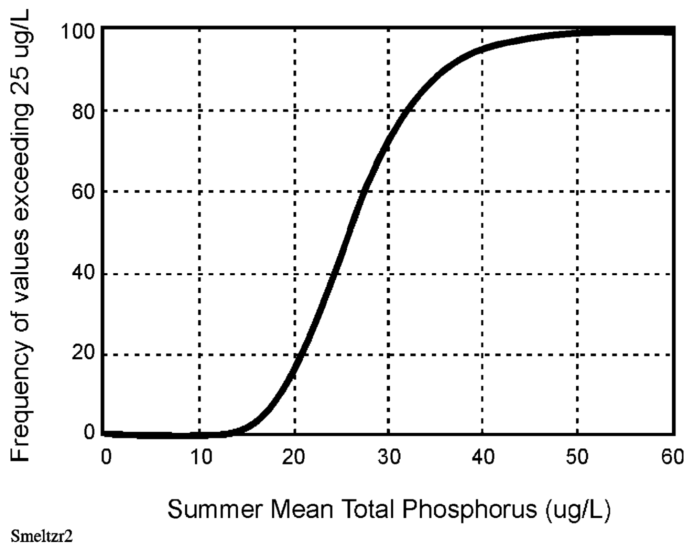

Figure 2. Relationship between the summer mean total phosphorus concentration and the frequency of occurrence of instantaneous nuisance values (greater than 25 µg/L) at Lake Champlain water quality monitoring stations.

A mean total phosphorus criterion of 14 µg/L was established for seven segments of Lake Champlain, as shown in Table 2. In other lake segments, higher or lower criteria values were established based on limitations of practical attainability, or to provide antidegradation protection where existing phosphorus levels are below 14 µg/L. The Lake Champlain phosphorus criteria listed in Table 2 were adopted by rule as part of the Vermont Water Quality Standards in 1991, and were later endorsed as joint management goals for Lake Champlain in a water quality agreement signed by New York, Quebec, and Vermont (Lake Champlain Phosphorus Management Task Force, 1992).

The user survey analysis provided a reasonably objective and empirically based method for deriving phosphorus criteria to protect recreational use and enjoyment of Lake Champlain. However, several limitations of the approach should be noted. The user survey was not based on a randomly chosen sample of public opinion, and should not be used to assess the general impressions of Lake Champlain water quality by the entire user public. Other potential eutrophicaion impacts such as shoreline periphyton and aquatic plant growth, hypolimnetic dissolved oxygen depletion, fisheries impacts, and water supply impairment were not considered in deriving the phosphorus criteria for Lake Champlain. The approach assumed that the instantaneous phosphorus value was an appropriate surrogate variable for the more direct causes of eutrophication nuisances such as high algal densities. Finally, a comparison of user survey results in Vermont and Minnesota revealed striking regional differences in user perceptions of lake water quality (Smeltzer and Heiskary, 1990). If a user survey approach is to serve as a basis for developing lake water quality criteria, then the data should be as specific to the lake region of concern as possible.

Table 2. Total phosphorus criteria for Lake Champlain segments, compared with currently existing mean values. The criteria are applied as summer or annual mean values in central, open-water regions of each lake segment (Vermont Water Resources Board, 1996; Lake Champlain Phosphorus Management Task Force, 1993). Current levels are from Smeltzer and Quinn (1996).

Lake Segment	Criterion Value (µg/L)	Current Level (µg/L)
Main Lake	10	12
Malletts Bay	10	9
Shelburne Bay	14	15
Burlington Bay	14	13
Cumberland Bay	14	14
Northeast Arm	14	14
Isle La Motte	14	12
Otter Creek	14	15
Port Henry	14	15
St. Albans Bay	17	24
Missisquoi Bay	25	35
South Lake A	25	34
South Lake B	25	58

Application of the Criteria

A phosphorus budget and mass balance modeling analysis for Lake Champlain (Vermont DEC and New York State DEC, 1997; Smeltzer and Quinn, 1996) was used to determine the allowable phosphorus loadings from point and nonpoint sources in each state and each lake segment watershed. Optimization techniques were applied to the phosphorus mass balance model to find the minimum-cost set of watershed target loads that would attain the in-lake criteria listed in Table 2. Specific watershed phosphorus loading targets were then negotiated between the States of Vermont and New York and the U.S. Environmental Protection Agency. The loading targets and a 20-year implementation timetable were incorporated into a comprehensive plan for the Lake Champlain Basin prepared by the Lake Champlain Management Conference (1996).

The phosphorus criteria developed for Lake Champlain were essential to the phosphorus management process for the lake. The criteria provided the basis for a negotiated political agreement on phosphorus reduction in Lake Champlain. The agreement was based on a quantitative modeling analysis and optimized implementation strategies. This analysis and agreement would not have been possible without the prior establishment of numeric, in-lake phosphorus concentration goals consistently between the three government jurisdictions.

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